EARTH SCIENCE SURVEY OF THE ROUGE VALLEY PARK

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EARTH SCIENCE SURVEY OF THE ROUGE RIVER VALLEY PARK

ABSTRACT

The proposed Rouge River Valley Park comprises 25 km^2 of crown and private lands located 40 km east of downtown Toronto in the City of Scarborough. The park contains the lower reaches of the Rouge River (21 km) and Little Rouge Creek (16 km) which drain toward the southeast into Lake Ontario. The rivers and their associated valleylands occupy about 20% of the park area, the remainder is a low relief, drumlinized tableland. Representative sections of mid-Ordovician shales (Whitby Formation) contained within the proposed park were originally identified by the Ministry of Natural Resources as Areas of Natural and Scientific Interest in 1983 (Cordiner 1983). In developing a comprehensive management strategy for the river valleys and intervening tablelands south of Steeles Avenue, it was important to assess in much greater detail the geological and geomorphological attributes of the proposed park.

The Rouge Valley is unique in the Greater Toronto Area in having outcrops of all the principal geological strata in the region. Certain strata are better exposed elsewhere (e.g. Scarborough Bluffs) but only the Rouge Valley exposes them all. Several of the Rouge Valley outcrops, such as that exposing sediments of last-interglacial age (*ca.* 125,000 B.P.), are of international significance. The modern landscape of the valley and surrounding tablelands is cut across thick glacial deposits laid down in the last glaciation. These deposits are up to 100 m thick and rest on last-interglacial sediments, and bedrock of Paleozoic age (around 420 million years). The Rouge Valley is deeply-entrenched into the glacial deposits and provides a rare glimpse of the bedrock surface. The area has attracted geologists and education groups for many years and is pre-eminently deserving of long term preservation and interpretation.

This report assesses and reviews the geological development of the park area and surrounding region, and identifies earth science features which are of local, regional and provincial significance. The features are ranked according to their values for public interpretive purposes; associated educational themes are identified.

The geological history of the park spans over 450 million years and encompasses a variety of depositional environments. The bedrock geology of the park records deposition of marine shales in a shallow, equatorial sea on the margin of the Appalachian mountains during the middle Ordovician (450 Ma). The shales contain a marine faunal assemblage which include representative fossils of the trilobite *Triarthus rougensis* and the graptolite *Climacograptus rougensis*. The park contains a provincially important type section for middle Ordovician strata (middle Whitby Formation).

A long period of non-deposition occurred until about 160,000 years ago when Quaternary ice age and warm, interglacial sediments were deposited across the park area. The park contains a representative section through ice age sediments present in the Toronto area and their associated landforms. A newly discovered outcrop of last interglacial sediments is of international significance; the only other section is poorly exposed in the former Don Valley brickyard. This Quaternary outcrop, and others, display prominent faults which may record seismic activity after the last interglacial period (Sangamon). Glacial sediments deposited during the last (Wisconsinan) glaciation are well exposed across the park area. Several glacial landforms in the park, including well developed drumlins and flutes, are of high interpretive value and can be used to illustrate the park's glacial history and record of climate change. A former, late glacial shoreline of an ancestral Lake Ontario (Lake Iroquois; about 12,000 years old) passes through the park and records a higher, ice-dammed lake level. The abandoned shoreline has been extensively mined for aggregates and is not well preserved.

The postglacial history of the park (the last 12 000 years) is recorded by suites of river terraces and by modern floodplain and valleyside features. Postglacial changes in the level of Lake Ontario are recorded by marshlands and a well-developed spit at the mouth of the Rouge River system.

No earth science features are presently highlighted and interpreted for the public anywhere in the Toronto region; the Rouge Park therefore provides a unique opportunity and is an excellent location for interpretive displays emphasising the regional geological development. Further urbanization of the upper catchment area of the Rouge Valley Park and its immediate margins close to Lake Ontario must be rigidly regulated if the present character of the Park's valleys, shores and streams is to be maintained and enhanced. Urban development in these areas will increase storm run-off and erosion, and result in greater sediment loadings in the river and decreased water quality, unless exceptional and innovative measures are implemented upstream. Valleyside slopes must be protected from deforestation; revegetation of slopes traversed by Hydro power corridors must be attempted to control sediment run-off to streams.

The park area contains a former landfill site (Beare Road; 1 km^2); this affords an excellent viewpoint of the park, has access roads in place, and should be considered as a location for earth science education and a conservation interpretive centre emphasizing the changing environments recorded by the geology of the Toronto region.

PREFACE

The Rouge Valley Park is an area of diverse geological features and history. Portions of it were identified as earth science Areas of Natural and Scientific Interest (ANSIs) during geological theme studies in 1982, and subsequently confirmed as such in the Ministry of Natural Resources' Maple District Land Use Guidelines (1983). As part of ongoing resource studies of provincially significant ANSIs, and as necessary resource analysis for the appropriate management planning of the proposed Rouge Valley Park, the following report was commissioned by the Ministry of Natural Resources. Field and laboratory studies were completed during the fall, winter and spring of 1990 and 1991.

Dr. Nick Eyles and Joe Boyce have undertaken intensive field surveys of the park area, and have built upon their broad knowledge of the geology of the surrounding region in compiling the inventory and evaluation of the park. Extensive traverses of all parts of the park were undertaken, with special focus on bedrock outcrops, stratigraphic exposures, sedimentary and lakeshore features, and surficial features in general.

This report is one of the series of geological and ecological inventories of significant natural areas of Ontario, designed to encourage land use activities appropriate to the natural features and ecological process of those areas. It was supported and supervised by the Ontario Ministry of Natural Resources.

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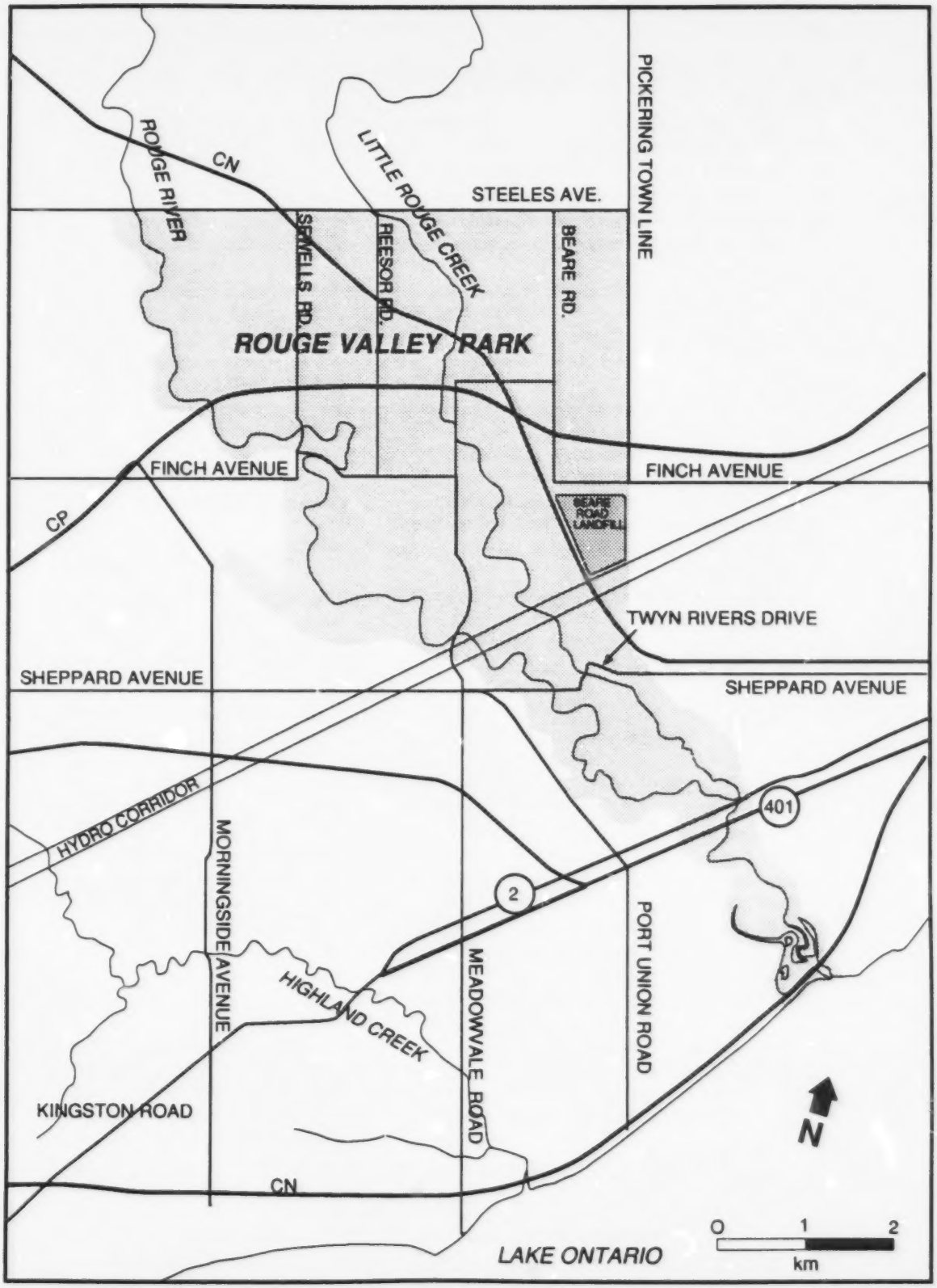


Figure 1.1 Location of study area.

CHAPTER 1: REGIONAL CONTEXT

1.1 Introduction

The Rouge Valley Park study area comprises about 25 km^2 of private, municipal and crown lands located some 40 km to the east of downtown Toronto, in the City of Scarborough (Fig. 1.1). The study area encompasses the land south of Steeles Avenue bounded by the Pickering Townline in the east and the crest of the Rouge River valley in the west. The area contains the lower reaches of the Rouge River (21 km) and Little Rouge Creek (16 km) which drain to the southeast into Lake Ontario. The rivers originate some 21 km to the northwest of the study area on the south slope of the Oak Ridges Moraine and are confluent just north of Highway 2 about 2 km inland of Lake Ontario. The streambeds, floodplains and valley slopes of the two rivers account for approximately 20% of the land area within the park. The river valleys are deeply entrenched in a low relief, drumlinized tableland covering most of the remainder of the study area.

Most of the study area can be accessed via regional roads and a well-established network of trails. Four major entry points into the park area exist at present: at the end of Lawrence Avenue (Rouge Beach park), on Kingston Road just west of the Rouge River (Glen Rouge park), along Twyn Rivers Drive, and on Old Finch Avenue east of the junction with Sewells Road (Fig. 1.1). The northern half of the study area is not as readily accessed since trail systems are not well developed and private lands are more frequent.

Some 8 km^2 of the study area, largely to the south of Finch Avenue, are parklands which are currently managed by the Metropolitan Toronto Parks Department, for the Metropolitan Toronto Region Conservation Authority (MTRCA). The present study area, the proposed Rouge Valley Park, also includes a substantial portion of lands owned by the Ministry of Government Services (MGS), as well as other private lands, especially in the area between Finch Avenue to Steeles Avenue. The Metropolitan Toronto Zoo and the adjacent Beare Road landfill site (1967-88) occupy some 4 km^2 south of Finch Avenue. Approximately 2 to 3 km^2 of the study area lies within a number of power corridors which are under the jurisdiction of Ontario Hydro (Fig. 1.1).

Selected areas within the park containing representative sections of middle Ordovician shales were identified as Areas of Natural and Scientific Interest (ANSI) by the Ministry of Natural Resources (MNR) in 1983 (Cordiner 1983). Life science ANSI status was also extended in 1983 to include most of the Rouge and Little Rouge River valleys and intervening tablelands south of Finch Avenue.

The earth science study of the proposed Rouge Valley Park was begun at the University of Toronto in November 1990 at the request of the MNR. The overall aim of the study was to provide the MNR and other participants in the park's management planning with an earth science resource database which would facilitate appropriate planning of the proposed park. The specific objectives of the study were:

i) To provide background information on the bedrock and surficial geology, and the geological evolution of the park within the context of the geologic history of the region;

ii) To provide an inventory of earth science features within the park area including exposed strata, landforms and physiographic features; and

iii) To identify areas and features of the park which are constraints to park development and which require appropriate planning or remedial measures to protect and preserve significant features.

The earth science study involved both laboratory and field work components. In the initial phase of the study, a synthesis of relevant literature and earth science data was carried out to guide the acquisition of new data and the planning of field work. Visits to the site were conducted in snow-free periods between November 1990 and

A THE GEOLOGIC TIME SCALE

ERA	PERIOD	EPOCH	MILLIONS OF YEARS B.P.	MAJOR LIFE FORMS
Cenozoic	Quaternary	Holocene	0.01 (10 000 yrs)	Mammals including humans in latest part Flowering plants
		Pleistocene	1.5	
	Tertiary	Pliocene	12	
		Miocene	20	
		Oligocene	35	
		Eocene	55	
		Paleocene	65	
Mesozoic	Cretacious	Numerous Epochs Recognized	130	Reptiles Conifers and cycads Advanced marine vertebrates
	Jurassic		186	
	Triassic		230	
Paleozoic	Permian	Numerous Epochs Recognized	265	Marine Vertebrates Fish (amphibians in later part) Marine plants (land plants in later part)
	Pennsylvanian		310	
	Mississippian		355	
	Devonian		413	
	Silurian		425	
	Ordovician		475	
	Cambrian		570	
Precambrian			800	Simple marine animals without mineralized skeletons, such as worms and jellyfish
			3500	Oldest fossils (bacteria)
			3800	Oldest known rocks
			4500	Formation of the solid earth
			5000	Formation of the proto earth

OLDEST ROCKS IN ROUGE PARK

B GEOLOGIC TIME COMPARED TO THE CN TOWER

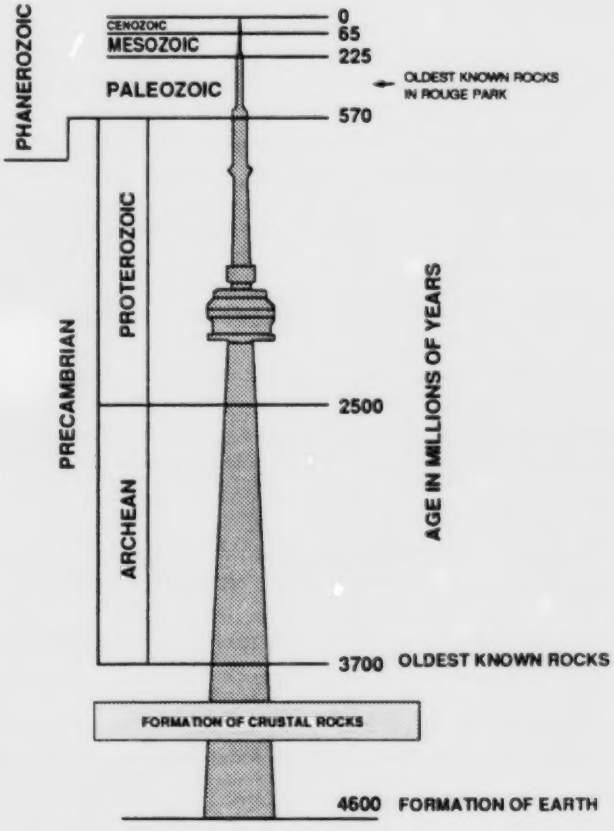


Figure 1.2 A. The geologic timescale.
B. Geologic time compared to the CN tower.

March 1991 during which the surficial geology, outcrop locations and geomorphic features of the study area were mapped at the 1:7,500 scale. Field data were combined with analysis of historical air photos (1:5,000, 1:10,000, 1:30,000 coverages) and existing maps of the regional surficial geology to identify terrain types and reconstruct the sequence of events leading to the development of the geologic and geomorphic features within the park.

The geology of the area encompasses changing depositional environments from two main time periods. The oldest, the Paleozoic era (Fig 1.2), is recorded by a sequence of 450 million year old Ordovician shales which form bedrock across the study area. These are covered by younger Quaternary sediments less than 1.5 million years old belonging to the Late Cenozoic era (Fig. 1.2). Rocks recording the time period between 450 and 1.5 million years are not found in the area as is the case with much of southern Ontario.

The regional context of the study was chosen so as to provide ample scope for the description of the geological evolution of the park area. With respect to the Quaternary Period (the last 2 million years), the regional setting was defined as the 'south slope region' which extends southward of the Oak Ridges moraine to the Lake Ontario shoreline. The landforms and surficial deposits of this region are the result of a recognizable continuum of geologic events involving the repeated growth and decay of large ice sheets and the development of high-level lakes in the Ontario basin. Most of these events have some expression in the geology of the park area. In discussion of the pre-Quaternary (in this case, the Paleozoic) evolution of the site, reference is made to a broader region which encompasses the Paleozoic lowlands of southern Ontario.

The regional geologic history is discussed with reference to Fig. 1.3 (A, B, C, D, E) and Appendix C.which summarize the key developments in these regions during the past 450 million years. The earth science features in the park area are treated under two headings 1) Bedrock (Paleozoic) Geology and 2) Surficial (Quaternary) Geology.

1.2 Bedrock (Paleozoic) Geology

The region is underlain by limestones, shales and dolostones of Ordovician age (Fig. 1.4). The distribution and geology of these sediments has been described in various reports of the Geological Survey of Canada (Liberty 1969), the Ontario Geological Survey (Hewitt 1972; Guillet 1979) and in the geoscience literature (Brett and Brookfield 1984; Bezys and Johnson 1988). The Ordovician strata form part of a southwestward thickening succession of Paleozoic sediments that unconformably overlies Precambrian Shield rocks exposed to the northeast of the region (Fig. 1.5). The Paleozoic strata dip towards the southwest at a low angle (< 1°) into a broad, northeast-trending structural low in the Precambrian basement termed the Appalachian basin (Figure 1.6). The basinward dip of the strata exceeds the gentle southward inclination of the bedrock surface, thus, successively younger sediments are exposed towards the southwest (Fig. 1.4, 1.5).

The Appalachian basin is one of a number of sedimentary basins in the eastern interior which accumulated thick sequences of terrestrial and marine sediments during the Paleozoic (Fig. 1.6). Sedimentation within these basin was associated with periodic downwarping and flooding of the eastern continental interior as a result of repeated episodes of uplift along the eastern margin of North America during the Taconic, Acadian, and Alleghenian orogenies (Fig. 1.3, A; Quinlan and Beaumont 1984). The sedimentation history of the Appalachian basin is dominated to large extent by the deposition of carbonates (limestones and dolostones) in shallow marine environments with episodic deposition of deep water shales during marine transgressions (flooding events). The Appalachian basin is presently separated from the Michigan basin in the west, by a broad, northwest-trending ridge in the Precambrian basement (the Findlay-Algonquin Arch) which forms the 'spine' of southwestern Ontario (Fig. 1.6). During middle Ordovician uplift (Taconic Orogeny) this arch was depressed such that the Michigan and Appalachian basins were interconnected.

Within the region, the base of the Paleozoic succession consists of middle and upper Ordovician limestones, dolostones and minor shales of the Simcoe group (Liberty 1969). These rocks form bedrock over a large area of southeastern Ontario (Fig. 1.4) and are exposed on the northeast shore of Nottawasaga Bay and along the Paleozoic/Precambrian contact between Midland and Kingston. The Simcoe Group is subdivided into four formations (Lindsay, Verulam, Bobcaygeon and Shadow Lake Formations) which have a cumulative thickness of about 200 m. To the southwest, these are succeeded by grey and black shales of the middle Ordovician Whitby and Georgian Bay Formations (Nottawasaga Group).

The Whitby Formation consists of fissile black, gray and blue calcareous and bituminous shales. These are exposed near Collingwood, at a number of locations on the Lake Ontario shoreline between Whitby and Oshawa, and along the banks and streambeds of the lower reaches of the Rouge and Little Rouge Rivers (Chapter 2.3.1) and Duffins Creek (Liberty 1969). The formation reaches a maximum thickness of about 100 m near Lake Ontario and forms bedrock over an area that extends some 70 km north of the shoreline and which includes the study area (Fig. 1.4).

The Whitby Formation is in turn overlain by alternating grey shales and thinly-bedded limestones of the Georgian Bay Formation. These rocks underlie Toronto as far west as Streetsville, and extend northward as a narrow belt (1-10 km) along the Niagara Escarpment to Georgian Bay (Kerr and Eyles 1991; Fig. 1.4). Surface exposures of the Georgian Bay Formation occur along the west side of Nottawasaga Bay and in the vicinity of Lake Ontario in a number of river sections between Toronto and Oakville (Humber, Mimico, Etobicoke, Credit, Bronte). The Georgian Bay Formation was formerly well exposed (up to 70 m vertical section) in the Don Valley Brickyard ANSI where it was once quarried extensively as raw material for brickmaking. The brickyard has since been infilled, leaving only the upper 4 m of the formation exposed. (The Georgian Bay Formation is also represented in the Workman Creek ANSI near Nottawasaga Bay.)

Within the region, the bedrock surface falls generally to the southeast from 180 m a.s.l near the southern margin of the Oak Ridges moraine to 60 m a.s.l. at the Lake Ontario shoreline (Fig. 1.7). The bedrock surface is gently undulating and is cut by a series of northwest-southeast trending channels which form part of a network called the 'Laurentian Channel'. The latter consists of system of broad, shale-floored topographic lows connecting the

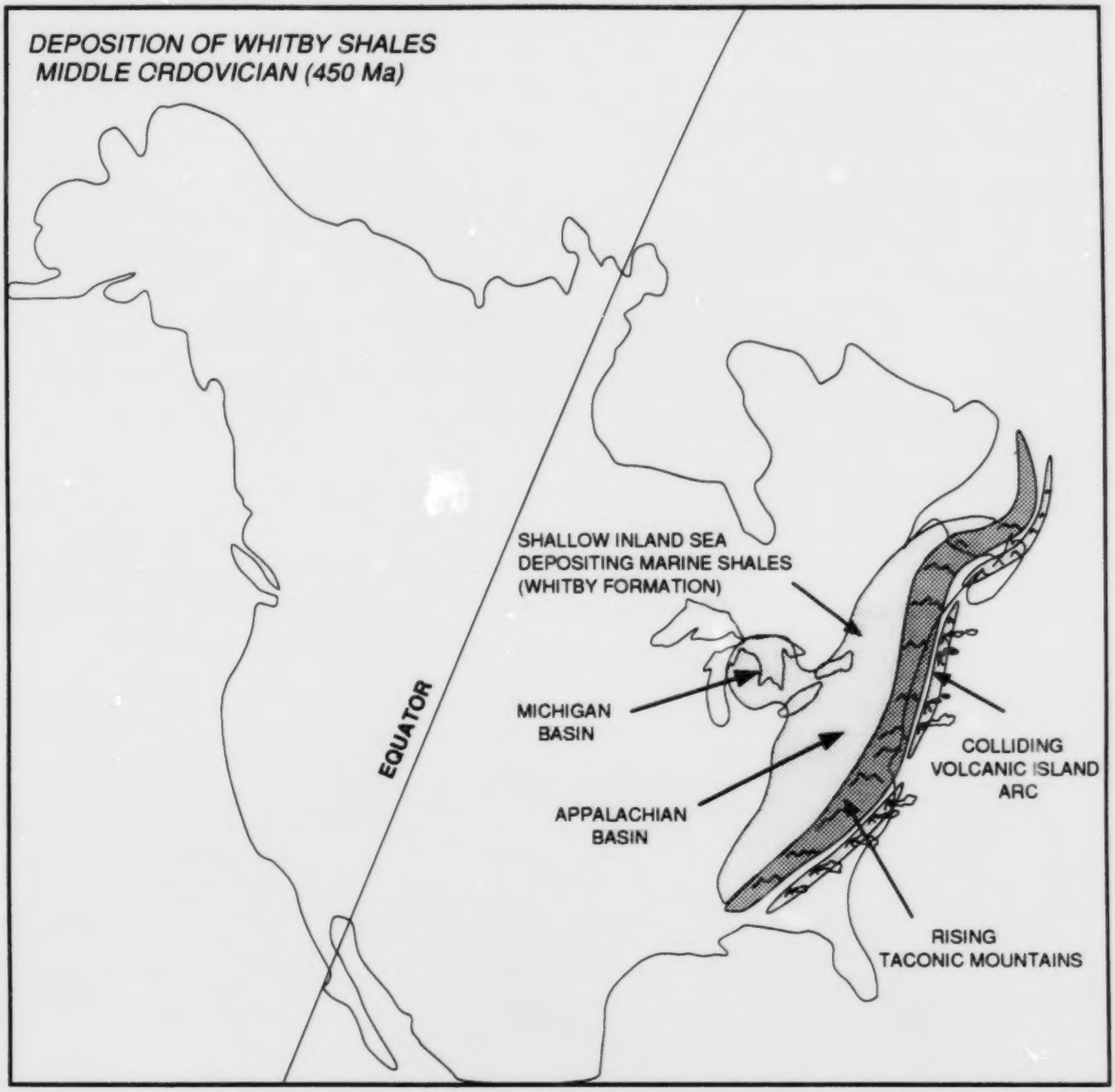


Figure 1.3 Geologic development of region:
A. Middle Ordovician flooding of continental interior in response to tectonic uplift along eastern seaboard. Deposition of Whitby shales in shallow inland sea.

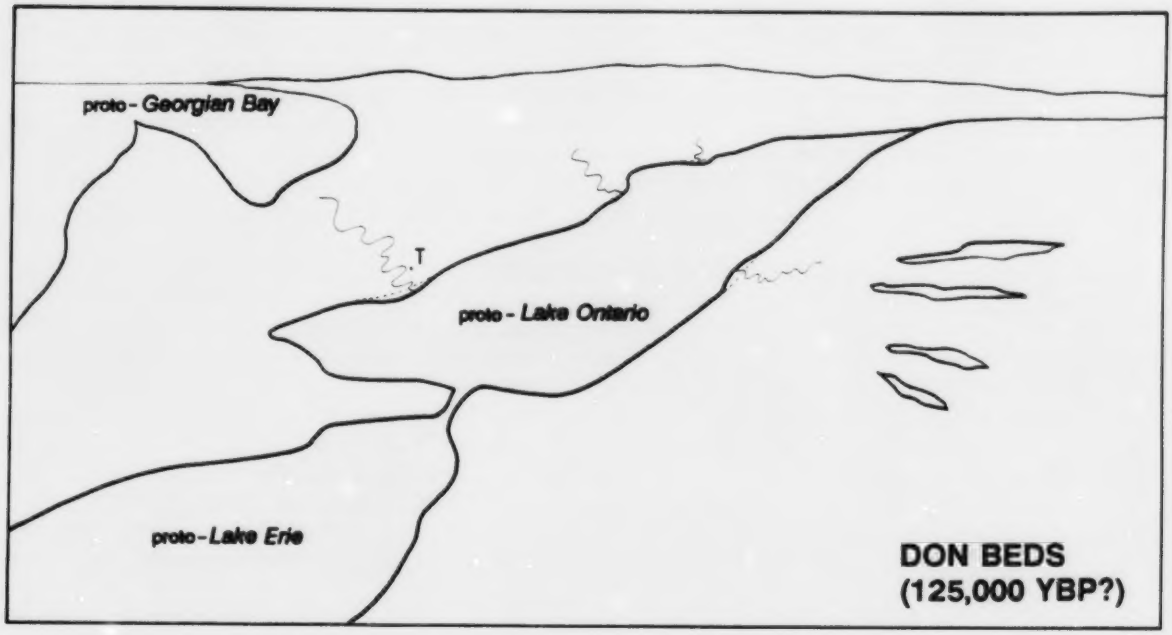
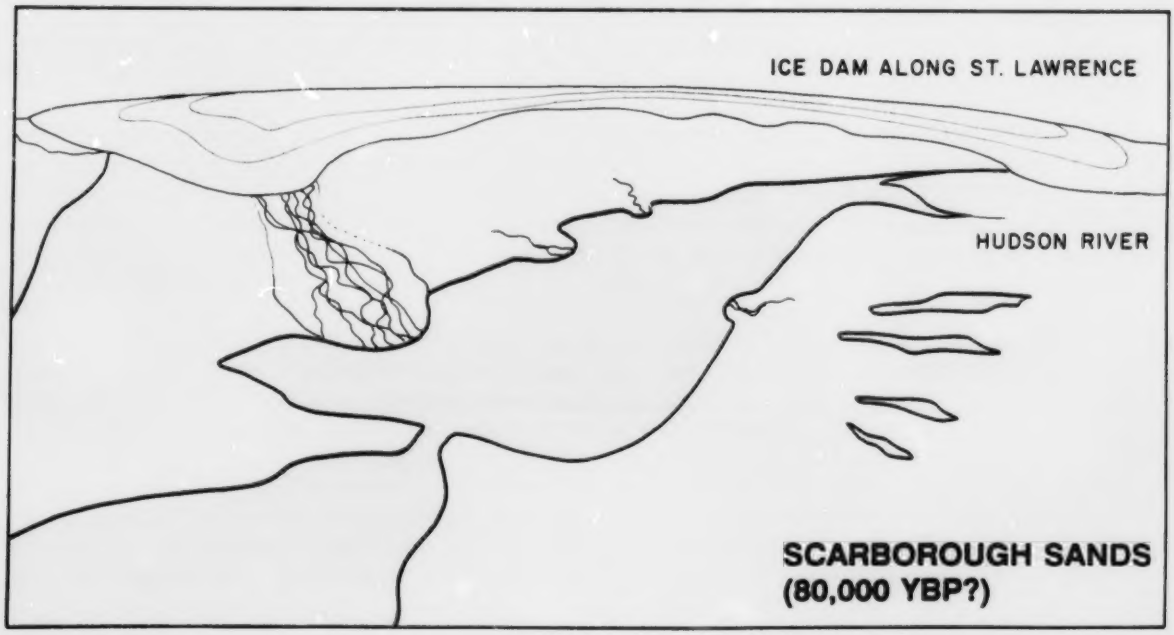


Figure 1.3 **B.** Deposition of Don Beds in ancestral Lake Ontario during last interglacial period (Sangamon) 120,000 B.P. (T: Toronto)



C. Formation of Scarborough delta across Toronto region as a result of blockage of the St. Lawrence outlet and rising lake levels during onset of Wisconsinan Glaciation, approximately 80,000 B.P.

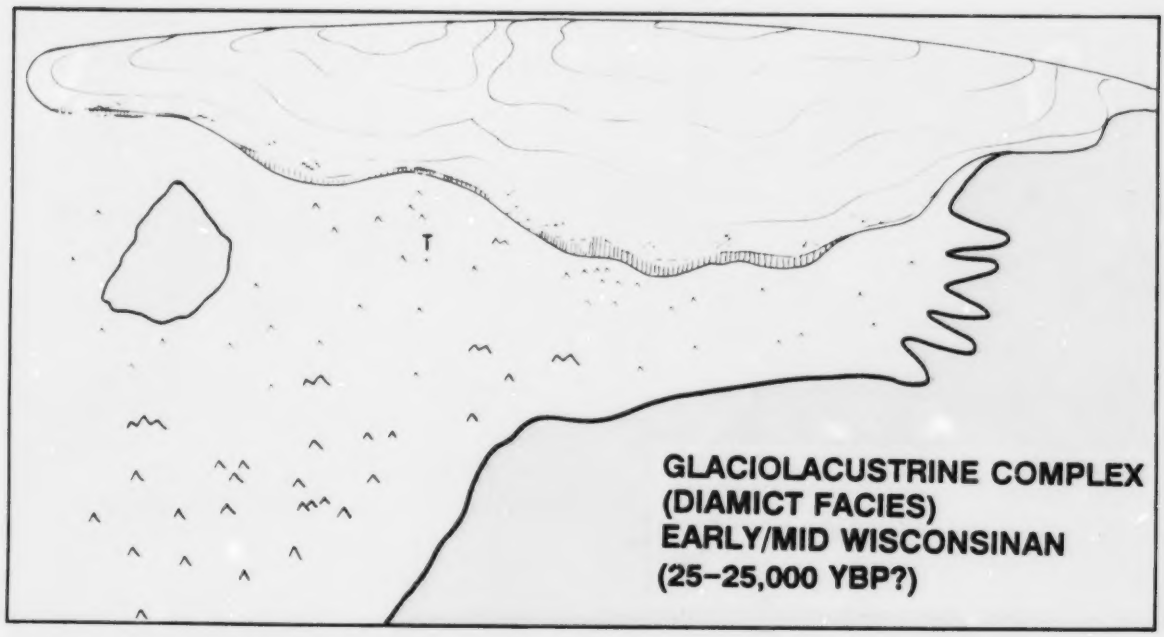
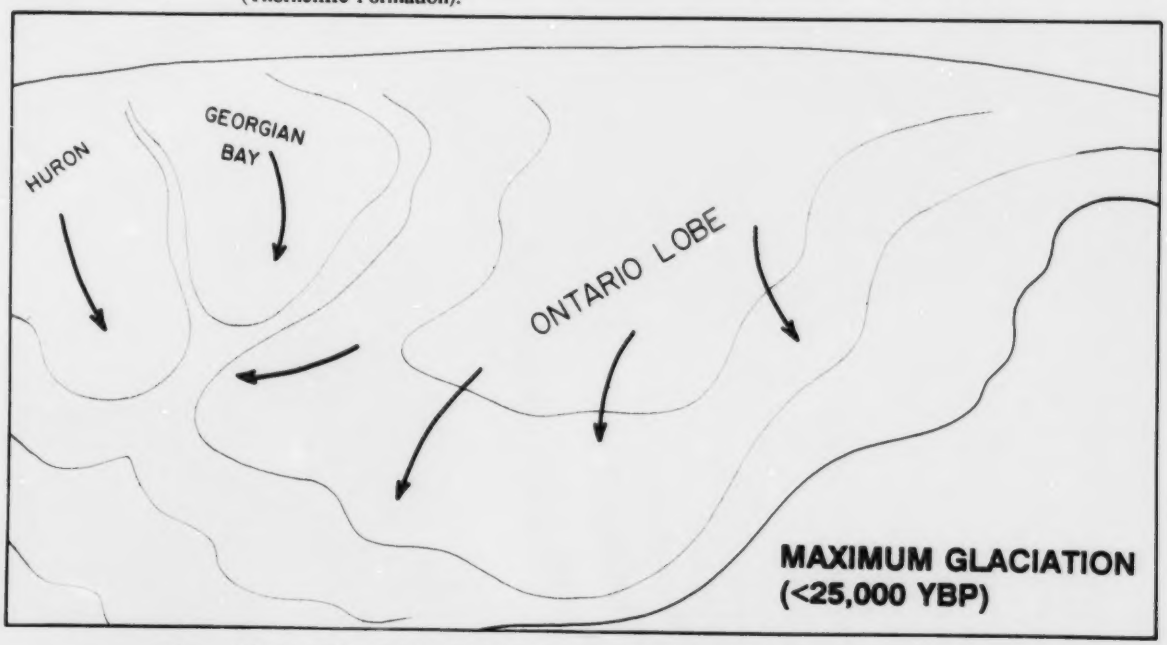


Figure 1.3 **D.** Formation of extensive proglacial lake with calving margin lying some distance to northeast of Toronto between 75,000 to 25,000 B.P. Deposition of stony muds on lake bottom (Sunnybrook, Seminary, Meadowcliffe diamicts) with repeated growth of delta into basin (Thorncliffe Formation).



E. Advance of Laurentide Ice Sheet across region and southward into Ohio during Late Wisconsinan about 25,000 B.P.

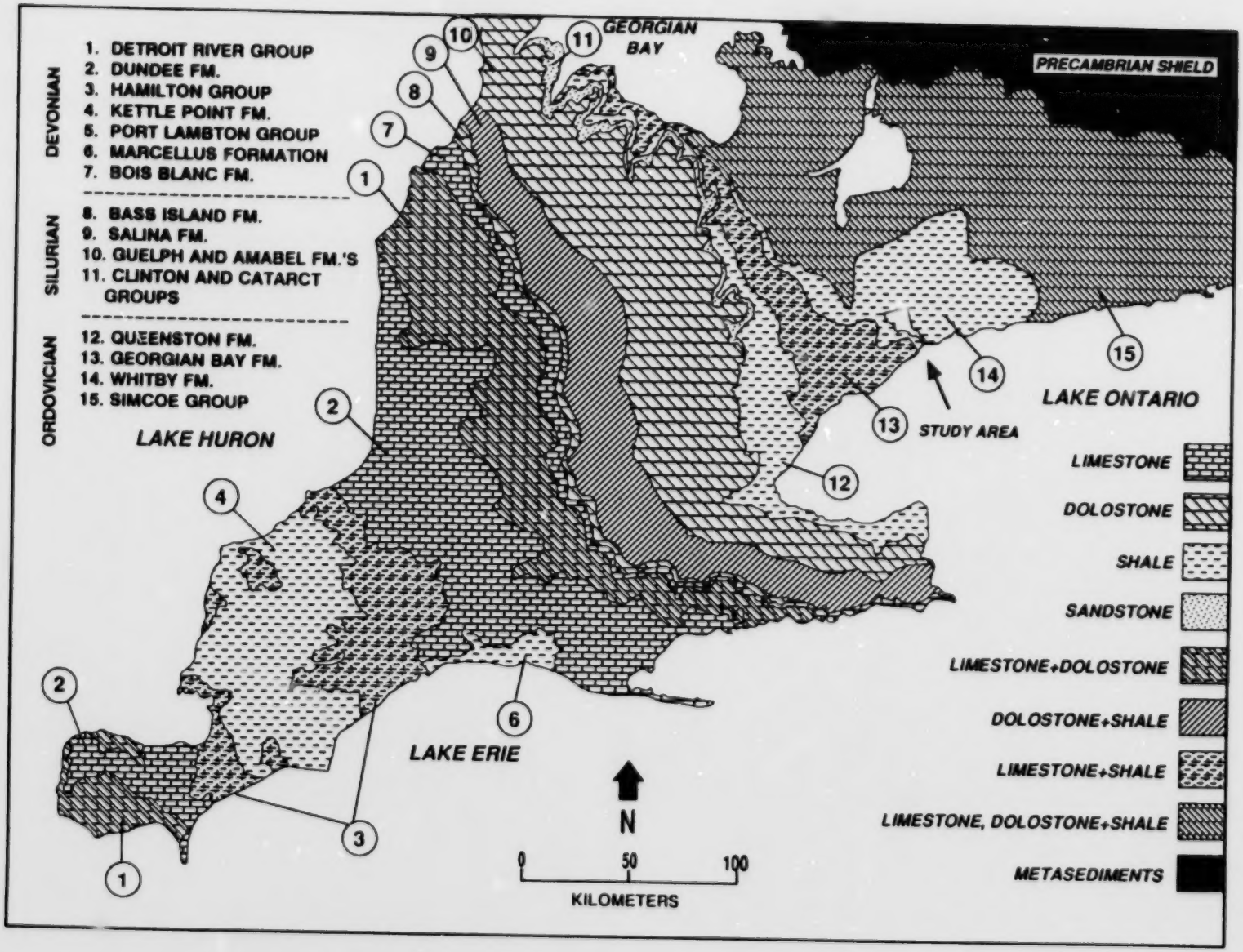


Figure 1.4 Bedrock geology of southern Ontario (modified from Freeman 1978).

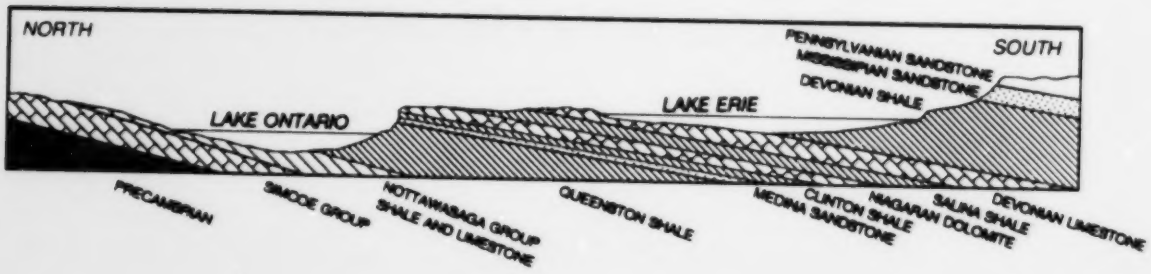


Figure 1.5 Geologic cross-section (N-S) through the L. Ontario and L. Erie basins (after Hough 1958).

Georgian Bay arm of the Huron basin with the northern margin of the Ontario basin (Rogers *et al.* 1961; White and Karrow 1971; Sibul *et al.* 1977; Eyles *et al.* 1987). The channel varies between 115 to 145 km in width and has been selectively overdeepened by glacial erosion into a series of channels up to 5 km wide (Fig. 1.7). The channel represents a major preglacial (presumably late Tertiary-early Quaternary) river system (Laurentian River; Spencer 1890; Flint and Locama 1986) which connected the upper Great Lakes to the Lake Ontario basin.

The present positions of the lower Great Lakes basins similarly reflect the differential erosion of Paleozoic sediments; lake basins occupy areas of weak shales scoured-out by successive glaciations while intervening upland areas and shorelines are formed in more resistant limestone and dolostone (Hough 1958).

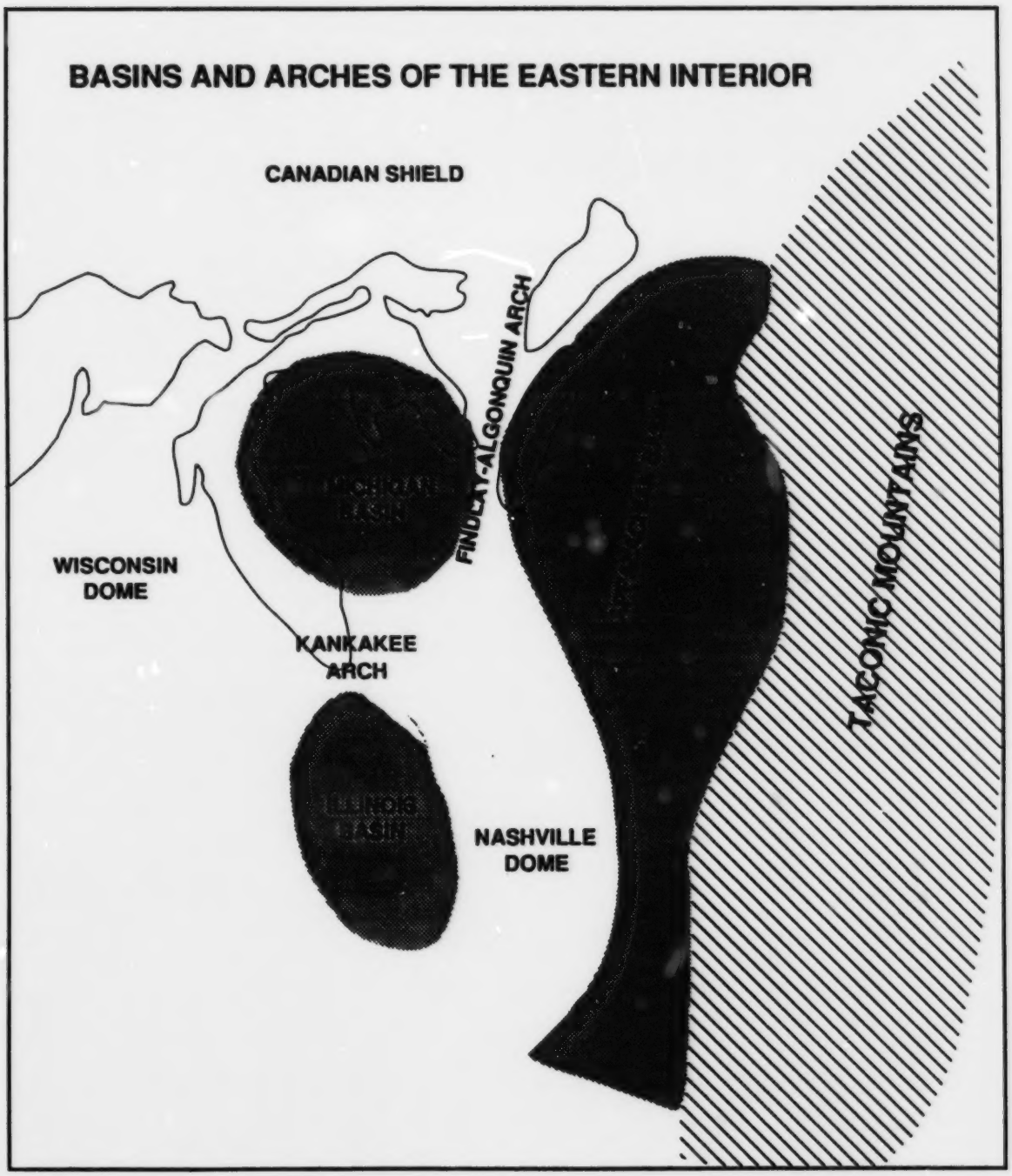


Figure 1.6 Basins and arches of the eastern interior (after Quinlan and Beaumont 1984).

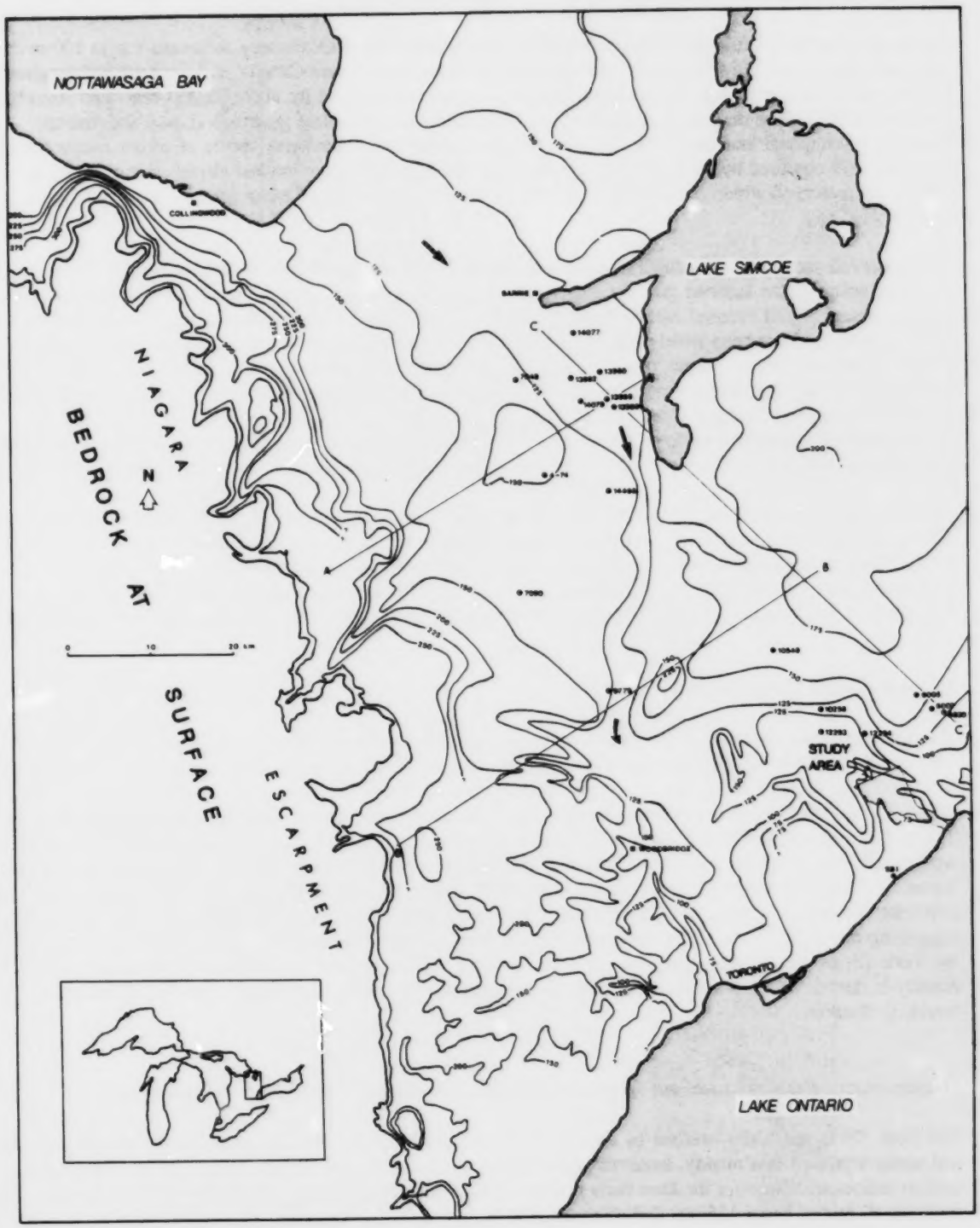


Figure 1.7 Regional bedrock topography showing location of Laurentian Channel (after Eyles et al. 1985a).

1.3 Surficial (Quaternary) Geology

The bedrock surface across the region is buried by a thick sequence of Quaternary sediments (up to 100 m thick) deposited during successive ice ages when large ice sheets developed over Canada, and intervening interglacial periods similar climatically to the present. Typically ice ages have lasted for about 75,000 years and interglacials for about 25,000. The deposits and landforms of the final stages of the last glaciation (Late Wisconsinan) dominate the regional landscape (Fig. 1.8) and to a large extent the sedimentary record of earlier events has been removed or is obscured by thick cover of glacial drift. Deposits pre-dating the last glaciation are, however, selectively preserved within the extensive network of bedrock valleys which make up the Laurentian Channel system (Fig. 1.9).

The preserved succession of sediments represents one of the longest Quaternary records in eastern North America, spanning the last two glacial cycles (Illinoian and Wisconsinan) and the intervening interglacial period (Sangamonian). Well exposed sections through the Laurentian Channel infill at Scarborough Bluffs and the Don Valley Brickyard have been widely employed as chronostratigraphic models for the late Quaternary (Fulton 1979; Karrow 1984) and are the subject of an extensive literature listed elsewhere (Karrow and Ochietti 1989). These outcrops have been studied by geologists since the 1880s; in particular, the work of A.P. Coleman (1852-1939), the first Professor of Geology at the University of Toronto is an internationally recognized milestone in the development of Quaternary geology in Canada (Eyles 1987b). The long history of glacial geological investigations has resulted in a diversity of local names for Quaternary stratigraphic units across the region (Appendix C).

Recent reconstructions of the subsurface stratigraphy of the Laurentian Channel infill (Eyles *et al.* 1985a; Eyles 1987a) indicate that a number of distinct depositional complexes can be recognized within the succession (Fig. 1.10). These complexes represent periods of relatively continuous sedimentation which are separated by erosional hiatuses and/or shifts in depositional environment. The scheme allows the Quaternary development of the region to be visualized as an 'event stratigraphy' which is discussed below and summarized in Appendix C.

Illinoian Glacial Complex (York Till)

The bottom of the Laurentian Channel is veneered by a variable thickness of shale-rich clayey-sand till (York Till; Terasmae 1960) which is presumed to record an Illinoian ice advance into the Ontario basin sometime prior to 125,000 B.P.(years Before Present). The boulder-rich character of the deposit and its pebble and magnetic fabric (Eyles 1987a) suggest a subglacial origin as a lodgement till deposited at the base of a moving ice sheet. The unit is well exposed 20 km north of Toronto at Woodbridge (Fig. 1.7) where it is penetrated by large ice-wedge casts that record an arctic climate, and is traceable southward in the subsurface over a large area of Metro Toronto. Along the Rouge River and in the Don Valley Brickyard, it is represented by a thin, bouldery lag overlying the bedrock (Eyles and Clarke 1988). The Don Valley site shows abundant broken mollusc remains suggesting reworking of the till in shallow water. Bedrock striations indicate that the ice sheet which deposited the York Till advanced basinward from the north (Karrow 1984). The unit is commonly exposed by construction activity in downtown Toronto and was of special concern during subway construction because of its dense, bouldery character.

Sangamonian - Early Wisconsinan Lacustrine Complex (Don Beds, Scarborough Formation)

The York Till is regionally overlain by the Don Beds (Sangamon interglacial), a warm-climate sequence of clay and sands deposited in a muddy, lacustrine shoreface of an ancestral Lake Ontario (Fig. 1.3.B). There are no precise radiometric dates for the Don Beds but amino-acid determinations are compatible with a Sangamon (last interglacial) age of about 125,000 B.P. (Karrow, 1984).

Before the present report, the Don Beds were thought to be exposed only in the Don Valley brickyard but a new exposure was found along the Rouge Valley. These beds are of international importance in that they are richly

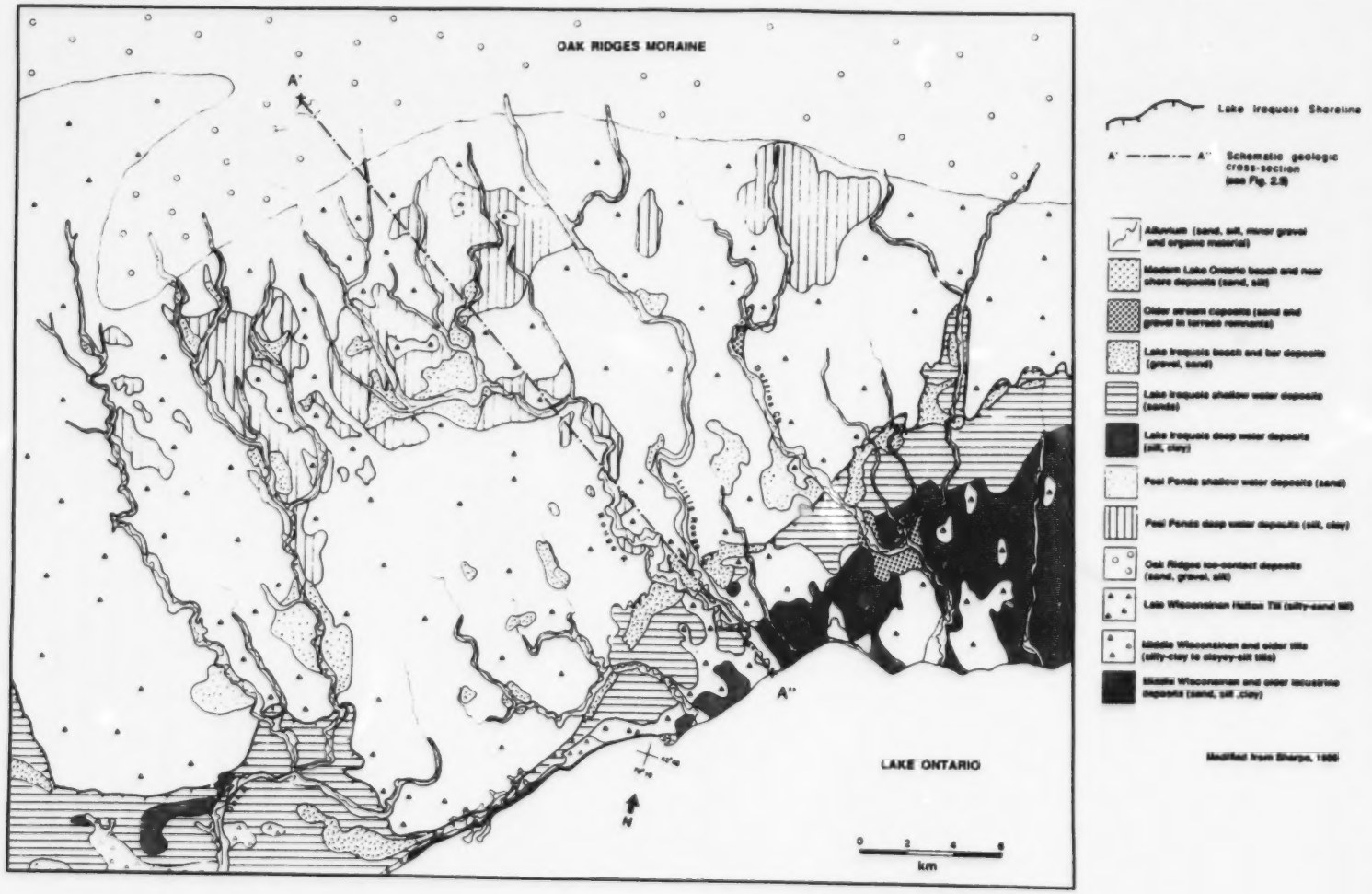

OAK RIDGES MORAINE
A'
A''
LAKE ONTARIO
N
0 2 4 6
km
Lake Iroquois Shoreline
A' — A'' Schematic geologic cross-section (see Fig. 2.9)
Alluvium (sand, silt, minor gravel and organic material)
Modern Lake Ontario beach and near shore deposits (sand, silt)
Older stream deposits (sand and gravel in terrace remnants)
Lake Iroquois beach and bar deposits (gravel, sand)
Lake Iroquois shallow water deposits (sands)
Lake Iroquois deep water deposits (silt, clay)
Peel Ponds shallow water deposits (sand)
Peel Ponds deep water deposits (silt, clay)
Oak Ridges ice-contact deposits (sand, gravel, silt)
Late Wisconsinan Halton Till (silty-sand till)
Middle Wisconsinan and older tills (silty-clay to clayey-silt tills)
Middle Wisconsinan and older lacustrine deposits (sand, silt ,clay)
Modified from Sharpe, 1980

Figure 1.8 Regional surficial (Quaternary) geology (modified from Sharpe 1980).

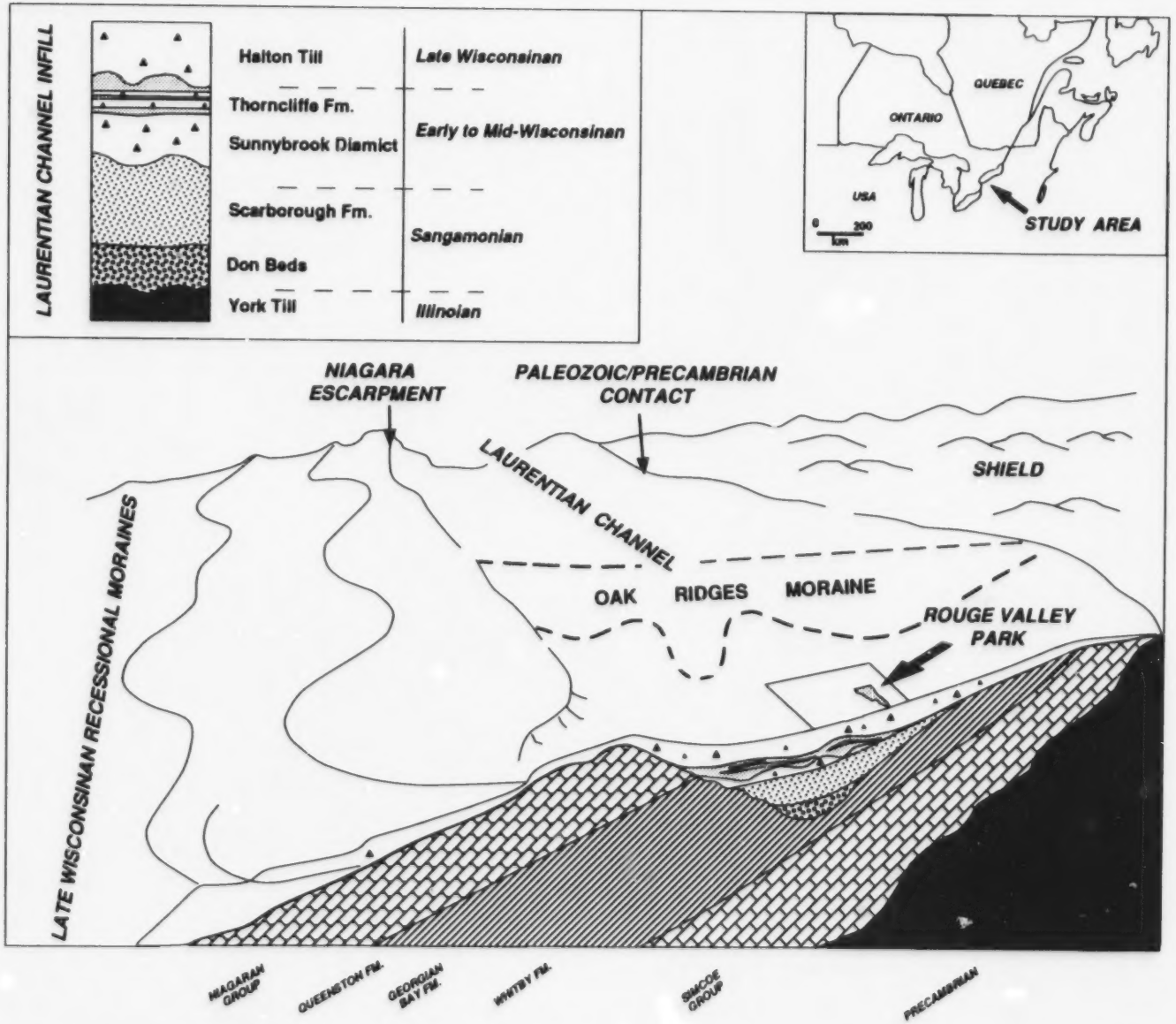


Figure 1.9 Schematic cross-section through Laurentian Channel infill at Toronto.

fossiliferous and therefore allow reconstructions of the last interglacial's climate, vegetation and fauna. The wider significance of these deposits is discussed at length by Eyles and Williams (1992). The brickyard exposure is now badly eroded, and not easily accessible to the public, visiting scientists or educational groups, and its future is uncertain.

At the Don Valley brickyard, which has been extensively studied, the Don Beds comprise 6 m of alternating fossiliferous muds and sands which rest on a bouldery lag formed by the subaqueous reworking of the York Till. Mud strata show extensive bioturbation by amphipods, oligichaetes, and nematodes and contain abundant peat lenses, plant macrofossils (macerated plant tissue, packed leaves, flattened wood fragments, occasional logs) and faunal remains (giant beaver, groundhog, brown bear, bison, mastodon) possibly carried into the lake by an ancestral Don River. The thickness and number of muddy strata increases upwards in section, comprising a well-developed fining-upwards sequence. The intervening sand beds are up to 1 m thick, contain abundant pelecypod and gastropod valves and show well developed hummocky and swaley cross-stratification truncated by wave ripples draped with mud.

This succession has been interpreted (Eyles and Clarke 1986, 1988) as a record of storm wave activity with subsequent periods of fairweather on a shallow (<2 m) lacustrine shoreface. The presence of caddisfly, diatoms, ostracods, cladocera and shallow water mollusc faunas within these beds (Williams and Morgan 1977; Poplawski and Karrow 1981; Hann and Karrow 1984; Eyles and Williams 1990) supports this interpretation.

The Don Beds are overlain by the laminated silty clays of the Scarborough Formation (Scarborough Clays; Terasmae 1960; Karrow 1969). The contact between the Don Beds and the clays is marked by an orange-stained sand which has been suggested to mark an unconformity between the two (Terasmae 1960). However, detailed study of these sediments and their contained pollen records (McAndrews 1985) suggests that they are a single, fining-upwards lacustrine sequence as originally suggested by Coleman (1933). The fining-upwards trend records an increase in the levels of the ancestral Lake Ontario and the commencement of deep water sedimentation, possibly as a result of downwarping of the basin during growth of the Laurentide Ice Sheet (Fig. 1.3, C). The latter comprised a continental-scale ice mass which expanded repeatedly to cover most of Canada and parts of the northern U.S. during the last glacial (Wisconsinan) cycle (Fig. 1.3).

Within the Don Valley Brickyard, the Scarborough Clays are truncated by channelized sands and gravels (Pottery Road Formation) which may mark a brief period of decreased lake levels and fluvial dissection of lacustrine sediments (Karrow 1967) or the growth of distributary channels fed by an advancing ice margin (Eyles 1987a). Elsewhere, the Scarborough clays grade transitionally upward into deltaic sands (Scarborough sands) which reach a thickness of up to 60 m at Scarborough Bluffs. The top of the Scarborough delta lies at about 45 m above the modern lake level indicating it was built into a high-level lake, possibly dammed by ice blocking the St. Lawrence outlet to the east. These sediments can be traced in the subsurface over a considerable area of the Laurentian Channel (Fig. 1.9).

Studies of pollen (Terasmae 1960; McAndrews 1985) and plant macrofossils (Kerr-Lawson 1985) from the lower part of the Don Beds indicate that the area supported a diverse deciduous forest including oak (*Quercus*), elm (*Ulmus*), birch (*Betula*), ironwood (*Ostrya/Carpinus*), maple (*Acer*), basswood (*Tilia*), cedar (*Thuja*), beech (*Fagus*), hickory (*Carya*), poplar (*Populus*), sweet gum (*Liquidambar*) and willow (*Salix*). In the upper part of the sequence, near the contact with the overlying Scarborough Formation, a decline in the number of deciduous species is noted with pine (*Pinus*), spruce (*Picea*), alder (*Alnus*) and birch (*Betula*) becoming dominant.

Paleoclimatic reconstructions (Fig. 1.11) based on these trends, together with other faunal and floral evidence (Eyles and Williams 1990), suggest a climate some 2° C warmer than present day (Terasmae 1960) during the deposition of the lower Don Beds, with a shift to cool, temperate conditions near the top of the sequence and during emplacement of the Scarborough Formation clays. Beetle faunas (Coleoptera) preserved in peat layers and channel fill deposits of the upper Scarborough delta indicate a shift to full boreal conditions (Williams *et al.* 1981), signalling the onset of the Wisconsinan Glaciation.

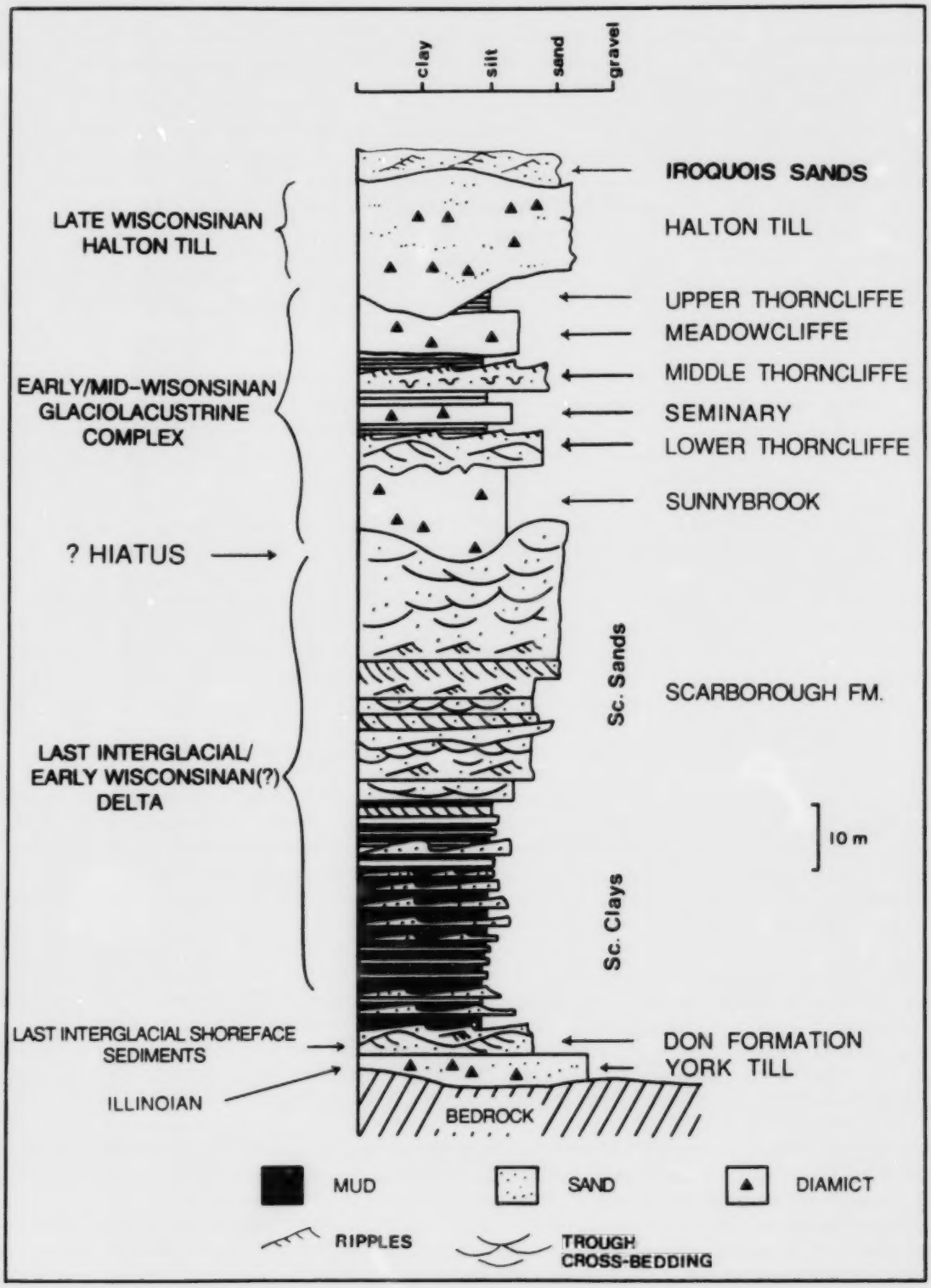


Figure 1.10 Schematic late Pleistocene stratigraphy of Toronto (after Eyles and Westgate 1987).

In the Don Valley Brickyard and along the Scarborough Bluffs the sediments of the Scarborough Formation have been cut into by broad (many 100s m) channels lined with gravels. Gravels were given the name Pottery Road formation by Karrow (1969) and attributed to changes in lake level. The gravels are locally fossiliferous.

Early to Mid-Wisconsinan Lacustrine and Glaciolacustrine Complex (Sunnybrook Till, Thorncliffe Formation)

The onset of the Wisconsinan Glaciation was accompanied by an abrupt rise in lake levels (up to 60 m), possibly in response to damming of the St. Lawrence outlet and the isostatic deepening of the Lake Ontario basin (Fig. 1.3, D). A sequence of pebbly mud units or 'diamicts' (poorly-sorted admixtures of mud to boulder size sediments known formally as the Sunnybrook, Seminary and Meadowcliffe Tills; Karrow 1984) interbedded with lacustrine deltaic silt and sand (Thorncliffe Formation) was deposited over the drowned Scarborough delta. The diamict units are generally fine-grained, show complex internal layering and are conformably interbedded with variably cross-bedded deltaic sands which contain abundant peat. These sediments are best exposed in a narrow outcrop belt along the Lake Ontario shoreline at Scarborough Bluffs (Fig. 1.8) and to the east between Bowmanville and Port Hope (Table 4).

The age of the assemblage is poorly constrained by a single thermoluminescence date of 66,000 ± 7000 B.P. obtained on silts associated with the Sunnybrook Till (Berger 1984) and an upper bounding radiocarbon age of 30,000 B.P. for peat extracted from the upper Thorncliffe Formation (Berti 1975). Macrofossils and pollen contained in the sands of the Thorncliffe Formation are indicative of a cool climate, forest-tundra environment (Berti 1975).

The interbedded diamict and sand sequence has traditionally been interpreted as a record of stadial (colder) and interstadial (warmer) climates which resulted in the repeated growth and decay of the Laurentide Ice Sheet throughout the Early to Mid-Wisconsinan period (Karrow 1967; Karrow 1983; Hicock and Driemanis 1989). Diamicts are inferred to be lodgement tills emplaced directly beneath grounded ice, separated by sands and silts deposited in lacustrine and fluvial environments during retreat of the ice sheet.

In contrast, other workers (Eyles and Eyles 1983; Eyles *et al.* 1985a; Eyles and Westgate 1987) have argued that the diamict-sand assemblage is the preserved bottom stratigraphy of a high-level, ice-contact lake. Pebbly muds (Sunnybrook, Seminary, Meadowcliffe "Tills") were accumulated on the lake bottom by the settling of fines (clay and silt) and ice-rafted stones, and were repeatedly buried by sands (Thorncliffe Formation) during the growth of a large deltas into the lake. Schwarcz and Eyles (1991) report geochemical studies of micro-fossils (ostracodes) contained in the diamict and which provide important paleoenvironmental data regarding water depths and temperatures. The shift from diamict accumulation to deltaic sedimentation may reflect changes in water depth as a result of crustal loading by sediments and ice, damming of the lake outlet, or changes in the rate and source of sediment supply.

This model, in contrast with earlier studies, predicts a restricted extent of the Laurentide Ice Sheet within the region during the Early Wisconsinan. The ice margin is inferred to have lain some distance to the northeast of Toronto (Eyles and Westgate 1987), and fully inundated the region only much later, during the Late Wisconsinan ice advance.

Late Wisconsinan Glacial Complex (Halton Till)

The Late Wisconsinan Laurentide Ice Sheet advanced into the region after 30,000 B.P and, at its maximum (21,000 B.P.), extended some 250 km south of Toronto into Ohio (Fig. 1.3, E). The ice margin fluctuated near its maximum for some 4,000 years (Driemanis and Goldthwait 1973) after which it began to recede and thin, splitting into a number of lobate ice masses which occupied the Great Lakes basins throughout much of the remaining Late Wisconsinan period. The latter was marked by a number readvances (stadials) of lobate ice

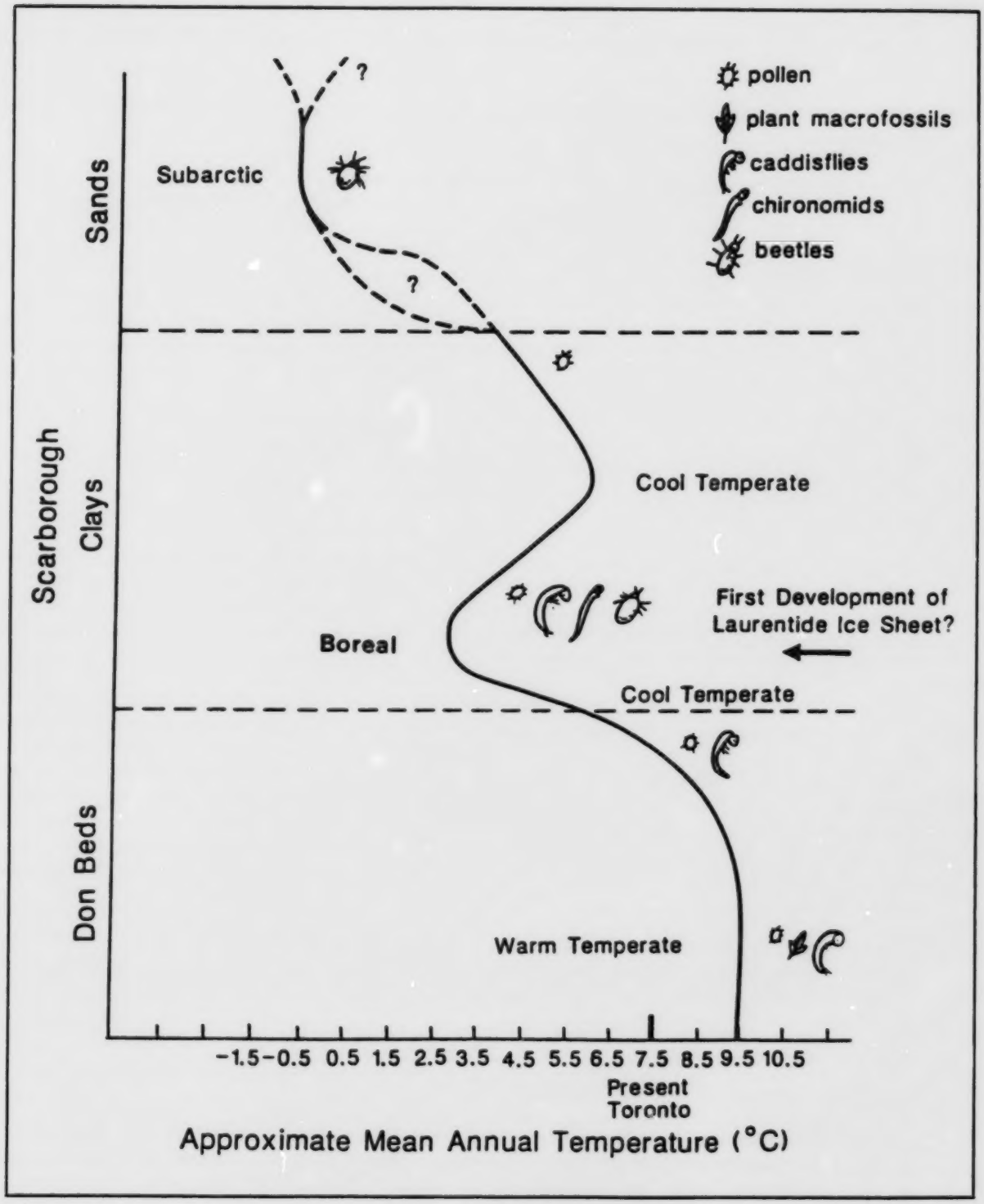


Figure 1.11 Record of temperature change during deposition of the Don Beds and Scarborough Formation as indicated by floral and faunal assemblages (from Eyles and Williams 1992).

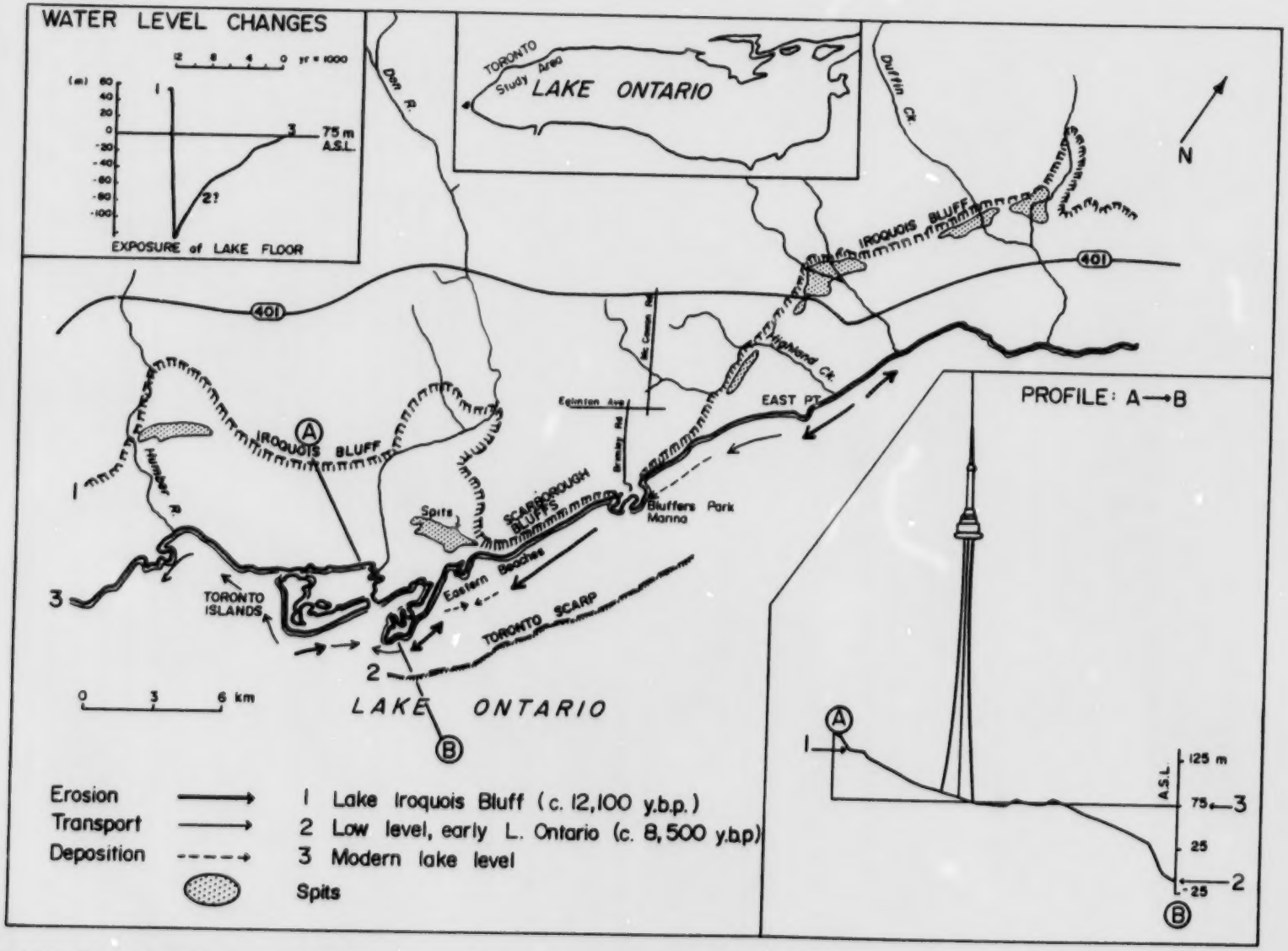


Figure 1.12 Regional extent of Iroquois bluff and drowned Toronto Scarp and postglacial changes in lake levels inferred from elevations of abandoned shoreline features (from Eyles *et al.* 1985b).

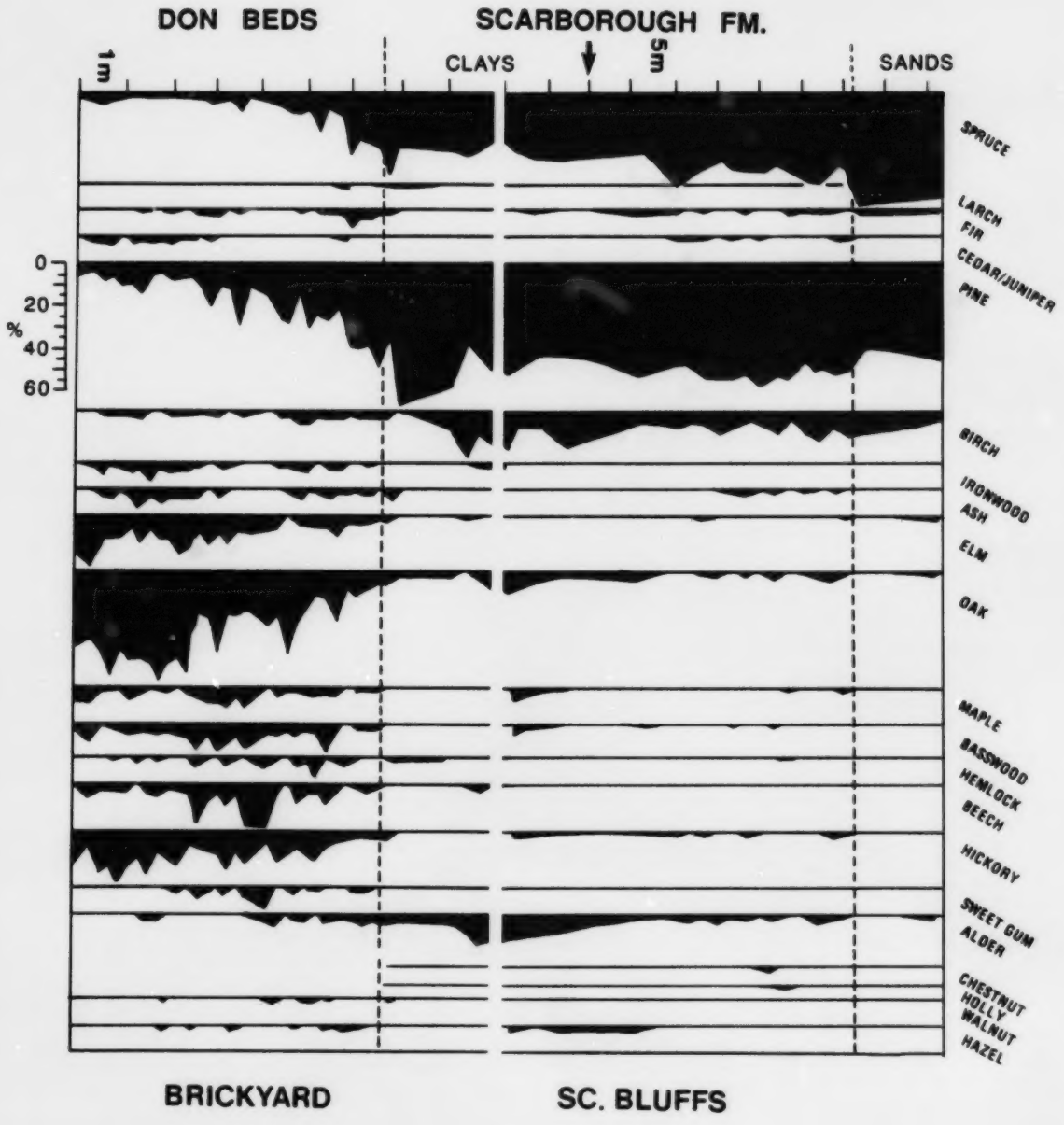


Figure 1.13 Tree pollen in the Don and Scarborough Formation shown as relative percentages. Note increase in cool and cold-climate conifer species (Spruce and Pine) upwards in sequence indicating climatic cooling.

streams over southern Ontario, separated by periods of limited ice extent (interstadials) during which large, proglacial lakes were impounded in the Great Lakes basins (Karrow 1984). Each readvance resulted in the reworking of sediments accumulated during preceding ice incursions, and consequently, the surface sediments and landforms of the region record only the last period of ice occupancy (*ca.* 13,000 B.P.) and subsequent deglaciation of the area (Sly and Prior 1984). Within the study region, the last readvance involved the expansion of the Ontario lobe out of the Lake Ontario basin to the northwest and the basinward extension of the Simcoe lobe from the Algonquin uplands in the northeast.

The Ontario lobe advance is recorded by a thick (up to 60 m) till sheet (Halton Till; Karrow 1974) which forms the dominant surficial material across the region (Fig. 1.8). The unit is typically a boulder-rich, silty-sand till with a sharply erosive base and a glacially streamlined (drumlinized and fluted) surface. The Halton till is interbedded with, and locally overlain by glaciofluvial and glaciolacustrine sediments which record meltstream sedimentation and the ponding of shallow lakes at the ice margin (Fig. 1.8).

The ice-marginal lake deposits associated with the ice retreat (Peel Ponds clay, silts and sands) occupy shallow depressions in the Halton Till surface and are generally less than a few metres in thickness. Well-developed terraces or other shoreline features are rarely associated with these temporary impoundments. Proglacial meltstream deposits similarly occupy low areas, often in swales between drumlins and flutings, and may occur as broad outwash plains, fans, or channelized deposits entrenched in the till surface. Many of the present-day rivers flowing into Lake Ontario follow ancestral meltwater drainage systems established during the retreat of ice from the region.

Significant accumulations (up to 100 m) of Late Wisconsinan outwash sediments, consisting mainly of sand and gravel with minor clays, are also found within the Oak Ridges moraine which lies some 50 km to the north of Lake Ontario (Fig. 1.8). The east-west trending drift ridge was deposited as a series of coalesced subaqueous fans built into a large lake dammed between the Ontario and Simcoe lobes (Gravenor 1957; Duckworth, 1979) sometime after 13,000 B.P. The moraine overlies an older stratigraphy consisting principally of glaciolacustrine sediments of possible Early to Mid-Wisconsinan age or older, which reach a thickness of up to 140 m within buried bedrock valleys (Laurentian Channel) beneath the ridge (Fig. 1.7). The total drift thickness in the moraine is over 300 m and represents the thickest sequence of Quaternary sediments in the province. The surface of the Oak Ridges moraine is characterized by a hummocky, kamiform topography produced by the meltdown of ice buried beneath ice-contact deposits.

Postglacial Lacustrine Complex (Iroquois Sands and Clays)

During the early phases of regional deglaciation, a high-level glacial lake (Lake Iroquois) formed in the Ontario basin after 12,500 B.P. (Muller and Prest 1985) as a result of maintained blockage of the St. Lawrence outlet. At its full extent, the lake stood approximately 60 m above the present level of Lake Ontario (Fig. 1.12) and drained southward into the Mohawk Valley via an outlet near Rome, New York (Sly and Prior 1984). Continued retreat of the ice led to the opening of the St. Lawrence outlet and a step-wise fall in lake levels after 12,000 B.P., producing a series of lower lake phases (Anderson and Lewis 1985).

Study of plant remains, pollen and aquatic fauna in Lake Ontario bottom sediments indicates that the lowest post-Iroquois level was attained by about 11,400 B.P. (Anderson and Lewis 1985). Water levels at this time were between 100 to 120 m below the present level of Lake Ontario. Subsequently, lake levels began to rise in response crustal rebound of the glacio-isostatically depressed St. Lawrence outlet, forming an early Lake Ontario. Evidence for this lower-level phase is recorded by a 30 m high, submerged bluff (Toronto Scarp; Fig. 1.12) lying parallel to the present shoreline about 3 km offshore. This scarp formed about 8,500 years ago by coastal bluff erosion at a time when lake level was some 60 m below the modern level (Eyles *et al.* 1985b). Water levels continue to rise in western Lake Ontario by about 0.23 m per 100 years (Clarke and Persoage 1970; Kite 1972; Flint *et al.* 1988) as a result of ongoing differential uplift of the eastern part of the basin.

A discontinuous bluff (up to 30 m in height) corresponding to the former shoreline of Lake Iroquois can be traced across the region (Fig. 1.12). The elevation of the bluff increases towards the east from 110 m a.s.l. (meters above sea level) at Hamilton, to 150 m a.s.l. east of Toronto and records the isostatic uplift of the eastern end of the lake basin. Coarse sands, gravels (up to 5 m thick) and bouldery lags truncate Late Wisconsinan and older deposits south of the strand line and delimit the extent of the Lake Iroquois beach. Southward of the relict beach, littoral sands and deep water silt and clay form extensive sand and clay plains which drape the surface of the Halton Till (Chapman and Putnam 1984). Fossil spits, similar to those produced by the westward longshore transport of sediment in present-day Lake Ontario (Greenwood and McGillvray 1978) can be identified along the Iroquois bluff. These have been extensively mined for sand and gravel; abandoned quarries are now occupied by landfill sites (Beare Road, Brock Road, Military Trail).

CHAPTER 2: GEOLOGY AND GEOMORPHOLOGIC DEVELOPMENT OF THE ROUGE VALLEY PARK

2.1 Physiography

The study area occupies approximately 25 km^2 on the 'south slope' physiographic region of southern Ontario (Chapman and Putnam 1984) which encompasses the area extending northward from Lake Ontario to the Oak Ridges moraine. Over two-thirds of the study area consists of a gently undulating tableland (Map 1) which falls generally in the direction northeast to southwest, attaining a maximum elevation of 175 m a.s.l near the northern boundary of the park and descending to lake level (75 m a.s.l.) at the mouth of the Rouge River. The remainder of the park area is occupied by the stream beds, floodplains, and side slopes of the Rouge and Little Rouge river valleys which are deeply entrenched (up to 30 m) in the surrounding tableland. The mean valley side slope is 40° and on most there is widespread evidence of unstable slope movements as indicated by inclined trees or soil erosion. The steepest slopes are largely bare of vegetation and expose sections through the surficial geology of the drainage basin.

The tablelands within the northern part of the study area lie within the Halton Till plain (Map 1) as defined by Chapman and Putnam (1984). The glacially streamlined topography of this area is the result of regional glaciation and entry of the Laurentide Ice Sheet into the region, beginning about 25,000 years ago (Chapter 1.3). Landforms across the till plain are the result of subglacial erosion and reworking of the ground surface beneath a lobe of the Laurentide Ice Sheet which advanced toward the north-west out of the Lake Ontario basin. Low, south-southeast to north-northwest oriented, elongated hills are drumlins and are characteristic of the gently undulating till plain surface.

The streamlined, drumlinized topography has controlled surface drainage patterns in the study area and is reflected in the north-northwest to south-southeastward flow of the Rouge Rivers and Little Rouge Creek. The southeasterly limit of the Halton Till plain is marked by relatively steep topographic gradients between elevations 145 and 175 m a.s.l. which define the shoreline of Lake Iroquois, a late glacial, ice-dammed, high-level phase of ancestral Lake Ontario (Chapter 1.3). The associated offshore deposits of Lake Iroquois form extensive sand and clay plains to the south of the abandoned shoreline. Lake Iroquois drained about 12,000 years ago during the final retreat of the Laurentide Ice Sheet (Sly and Prior 1984; Anderson and Lewis 1985).

2.2 Surface Drainage and Groundwater Resources

The Rouge River watershed occupies some 333 km^2 north of Lake Ontario (MTRCA 1989). It is a fan-shaped basin which converges from a width of 20 km near the southern margin of the Oak Ridges moraine, to 2.5 km at the Lake Ontario shoreline. The headwaters of the Rouge River and Little Rouge Creek originate on the southern flanks of the Oak Ridges moraine (Fig. 1.8) which comprises the regional surface and groundwater drainage divide, separating the Lake Simcoe and Lake Ontario drainage basins. The rivers flow southeastward in deeply entrenched valleys between 0.5 and 0.75 km in width which are cut as much as 30 m below the tableland surface. The rivers have a sinuous, meandering form and are confluent just north of Highway 2 about 2 km inland from Lake Ontario (Map 1). The park area includes the lower reaches of the Rouge River (21 km) and Little Rouge Creek (16 km) south of Steeles Ave.

The main branch of the Rouge River falls some 225 m from its headwater near Gormley (300 m a.s.l.) to the river mouth (75 m a.s.l) with a gradient which varies between 2 to 25 m km^{-1}. The stream profiles of the Rouge and its tributaries have a stepped configuration (Fig. 2.1) which reflects both changes in topographic slope and the differential erodibility of various Quaternary units which form the stream beds. The gradient of the streams is relatively high (5 - 25 m km^{-1}) in headwater regions, where they dissect the steep, kame topography of the southern flank of the Oak Ridges moraine.

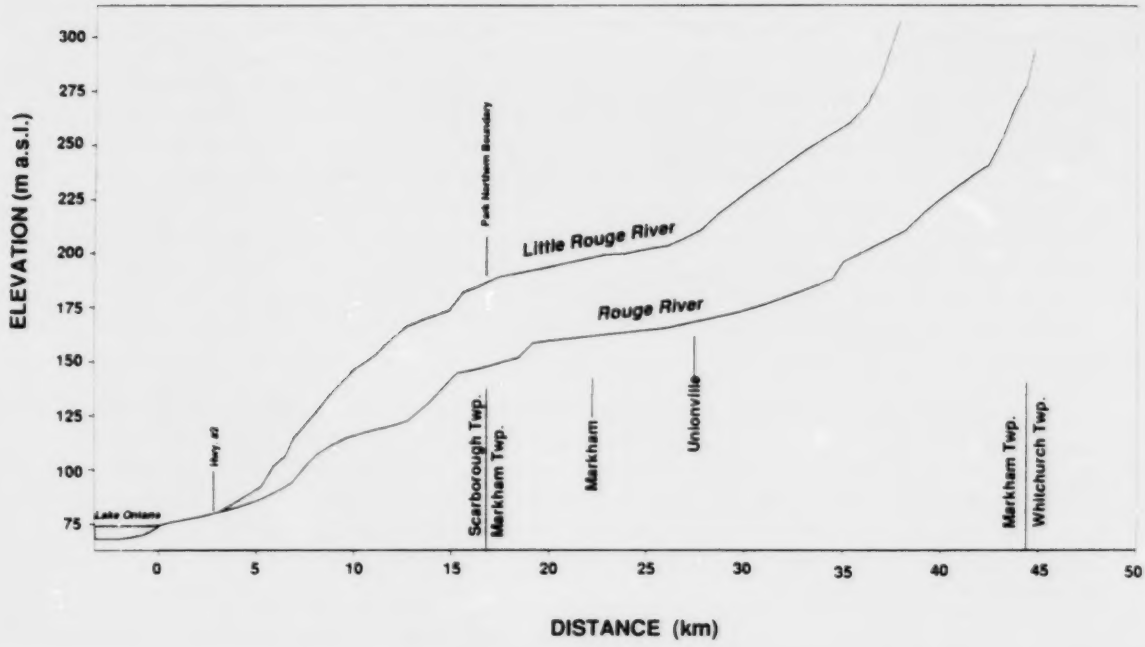


Figure 2.1 Stream profile along Rouge and Little Rouge rivers. Note stepped configuration of profile south of Scarborough/Markham boundary where rivers cut down through Halton Till and are entrenched in underlying older Early-Mid Wisconsinan deposits.

Further south, on the relatively erosion resistant and flat Halton Till plain, gradients are reduced (< 5 m km^{-1}) and streams are less deeply incised. Some 16 km up-river of Lake Ontario, a sharp increase in gradient is noted where the Rouge River and Little Rouge Creek penetrate the Halton Till and are entrenched in easily eroded sands of the Thorncliffe Formation (Map 2). Further southward, the stream profiles successively step down to lake level through the remaining Quaternary infill (Fig. 2.1) and become flattened where more resistant Ordovician shales form the stream beds.

The regional component of groundwater flow within the Rouge basin is generally southward, toward the lake and occurs principally within shallow and deep aquifer systems present in Quaternary sediments overlying bedrock (Sibul *et al.* 1977; Dillon 1988). Locally, overburden groundwater flows are deflected towards the Rouge River and Little Rouge Creek (Fig. 2.2) by steep surface topographic gradients and broad bedrock channels underlying the river valleys (Fig. 2.4). Groundwater flow in the shale bedrock underlying the basin is toward the southwest (Fig. 2.3), reflecting the gentle inclination of the strata in this direction. The shales are relatively 'tight' and impervious; active groundwater flow in occurs principally along discontinuities such as fracture zones and faults, and in the weathered upper surface of the shales (Dillon 1988).

Thick interstadial (Thorncliffe Formation) and interglacial sands (Scarborough Formation) comprise the primary water-bearing units within the Quaternary infill, and are bounded above and below by less permeable glacial strata (Sunnybrook, Halton tills) which represent aquitards (Fig. 2.5). Glaciofluvial sands and gravels of limited extent and continuity occur within the Halton Till and form localized aquifers in some parts of the basin. Locally-recharged, shallow aquifer systems are also associated with the Iroquois sands and gravels which cap the Halton Till south of the abandoned Iroquois terrace. In the study area, these discharge along the base of the Iroquois bluff and are locally significant in maintaining poorly-drained swamps and marshes (Map 1). Ponds occupying abandoned gravel pits along the base of the Iroquois bench are also fed by these systems.

Regionally, overburden aquifers provide important domestic and agricultural water supplies to a large number of communities including the rural areas in the northern parts of the proposed park. The thickness and areal extent of overburden aquifer systems within the Rouge basin and adjacent areas immediately to the east have been mapped by Sibul *et al.* (1977), Ostry (1979) and Dillon (1990). Within the northern park area, groundwater yields of 1 to 2 litres per second are obtained at depth from a southern extension of the Greenwood Aquifer system (Cedarbrae Aquifer) associated with the Thorncliffe sands. The aquifer discharges into the Rouge River as a series of springs and seeps occurring at the base of the Thorncliffe Formation where it crops out along the Rouge River valley north of Finch Avenue (Map 2). Deeper aquifers associated with the Scarborough Formation are also exploited extensively for groundwater resources in areas where sufficient yields are unobtainable from shallow systems. The Ordovician shales which form bedrock across the basin are relatively impermeable and do not constitute significant aquifers. The potability of bedrock waters is also reduced by naturally-occurring sulphides and dissolved iron derived from the shales (Sibul *et al.* 1977).

The deeper overburden aquifer systems are recharged regionally by waters infiltrating the thick sand and gravel complex (Oak Ridges Aquifer complex; Turner 1977) which comprises the upper part of the Oak Ridges moraine. The complex is unconfined along the crest of the ridge, but becomes confined southward where the less permeable Halton Till onlaps the moraine (Fig. 2.5). Surface springs and flowing wells (artesian) are common along the south slopes of the moraine where the steep topographic gradients and confined conditions result in piezometric heads above ground surface. In these areas, groundwater contributions to the headwater segments of streams (baseflow) can be as high as 94% (Roulet 1989).

The consistency of groundwater discharge and low temperatures of these streams is vital in the maintenance of habitats for cold water fish species such as brook trout and brown trout. The cold-water streams also support a number of commercial salmon and trout hatcheries. The potential loss of cold-water habitats as a result of urbanization and regional climate warming (e.g. Meisner 1990) is a pressing environmental problem. Baseflow contributions to the Rouge River and Little Rouge Creek from shallow aquifer systems in the central and lower parts of the Rouge basin are also significant, and have been estimated at 27-30% of the total stream flow (Sibul *et al.* 1977).

Plots of the relative concentrations of anions and cations of waters obtained at various depths in the subsurface have been employed to identify different groundwater types in the Rouge River basin (Howard and Beck 1986). Shallow (< 15 m) waters in the Iroquois sands and Halton Till are characterized by calcium bicarbonate waters typical of freshly recharged groundwater, where dissolution of dolomite and calcite by mildly acidic precipitation is the predominant process. Below 15 m there is a transition to sodium bicarbonate waters due to cation exchange processes, involving the substitution of sodium for calcium. These waters are typical of regional groundwaters originating in the recharge area of the Oak Ridges moraine.

The quantity and quality of groundwater resources in the Rouge basin is increasingly being impacted by urban development and related activities. Of particular concern is the degradation of groundwater quality and the disruption of recharge areas in the hydrogeologically significant Oak Ridges moraine. The quality of moraine recharge waters is threatened by numerous contaminant sources including urban runoff, industrial and agricultural effluents, leakage from underground septic systems and storage tanks, road de-icing chemicals and landfill leachates.

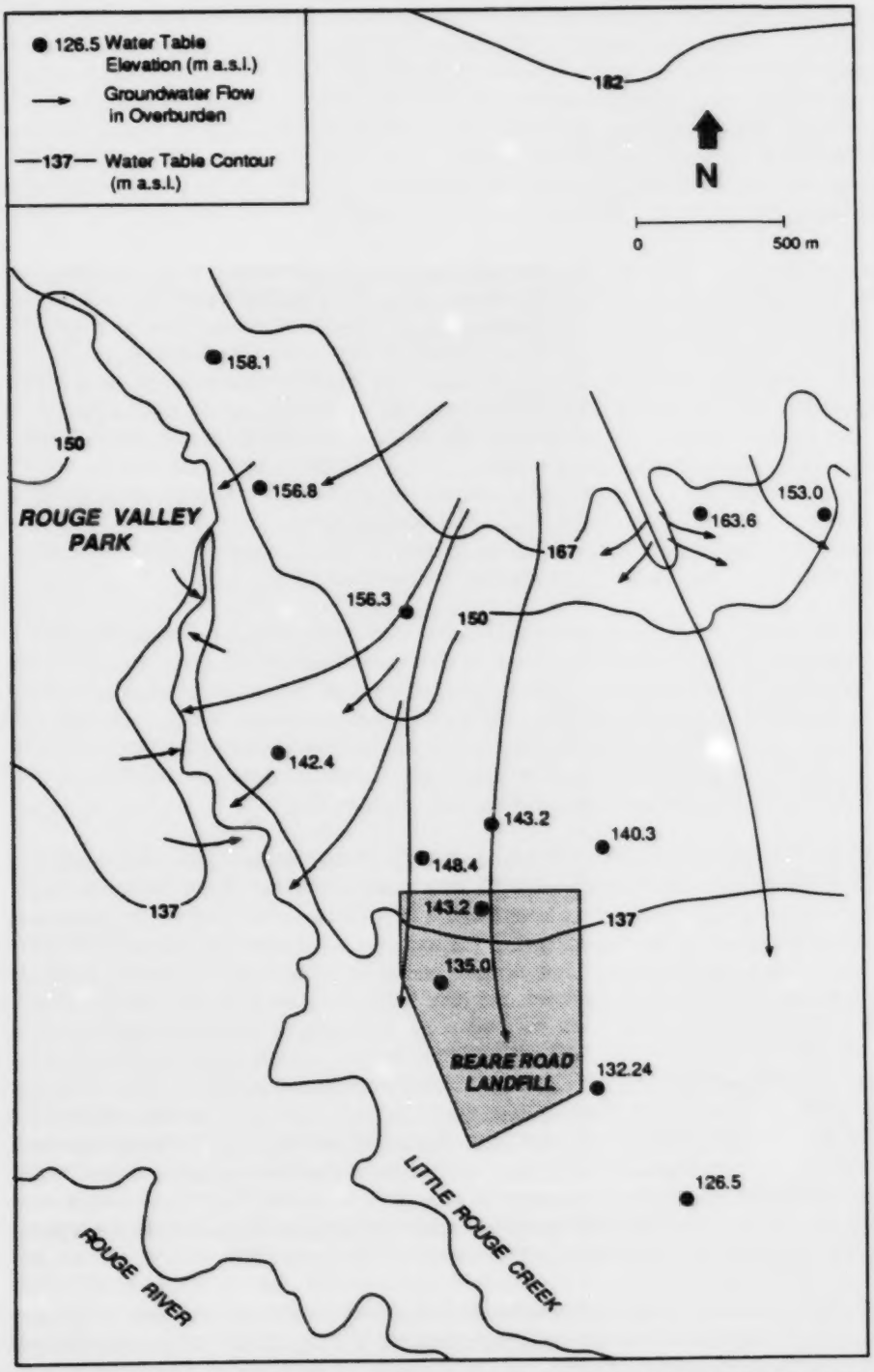


Figure 2.2 Groundwater flow in overburden in northeastern part of study area (after Dillon 1988). Groundwater paths are locally deflected toward rivers by steep surface gradients and bedrock valleys associated with watercourses. Flow paths demonstrate potential for contamination of rivers via groundwater inputs; potential contaminant sources include leachates from the Beare Road landfill and other surface pollutants (e.g. road salt dumped on Twyn Rivers Drive).

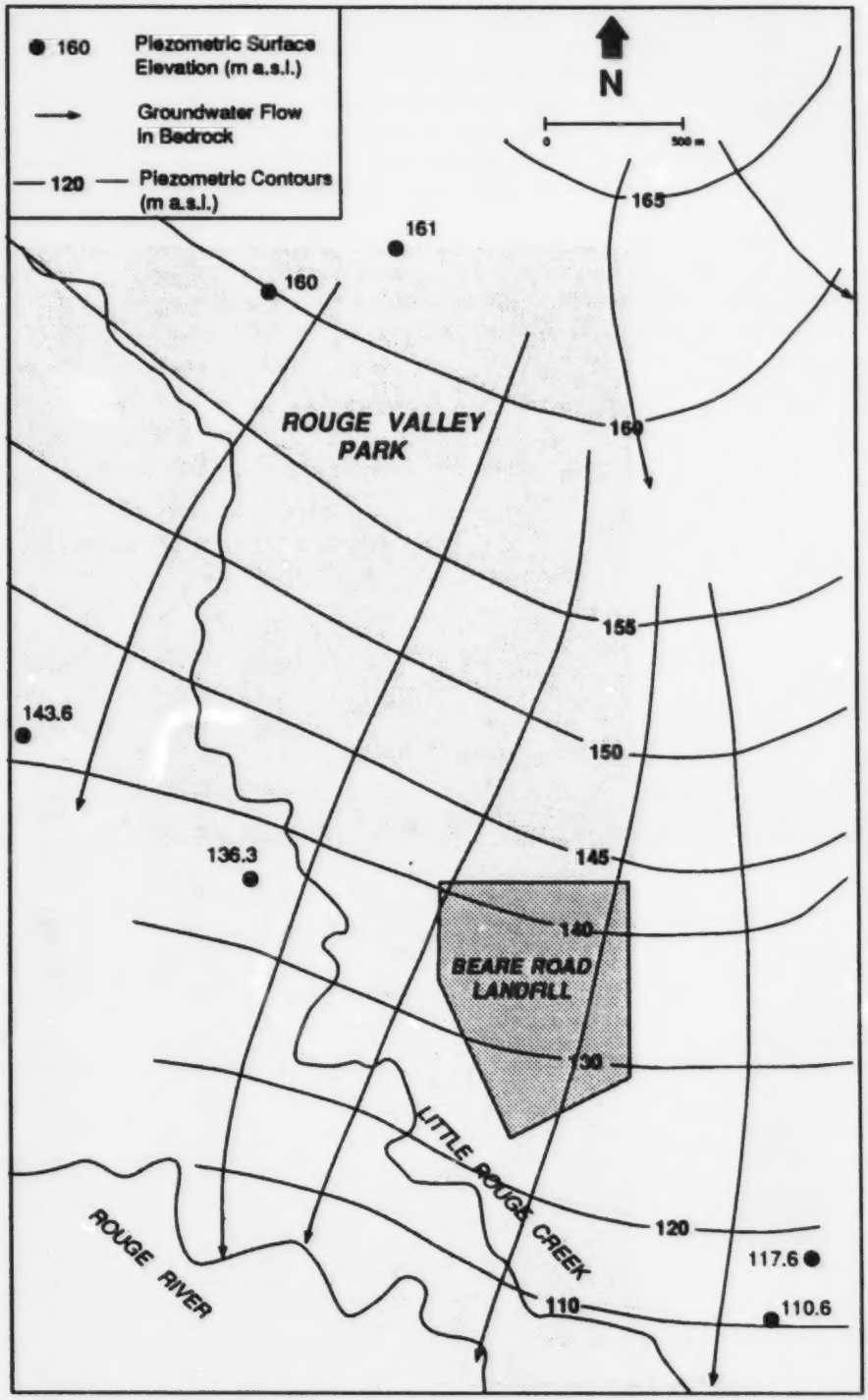
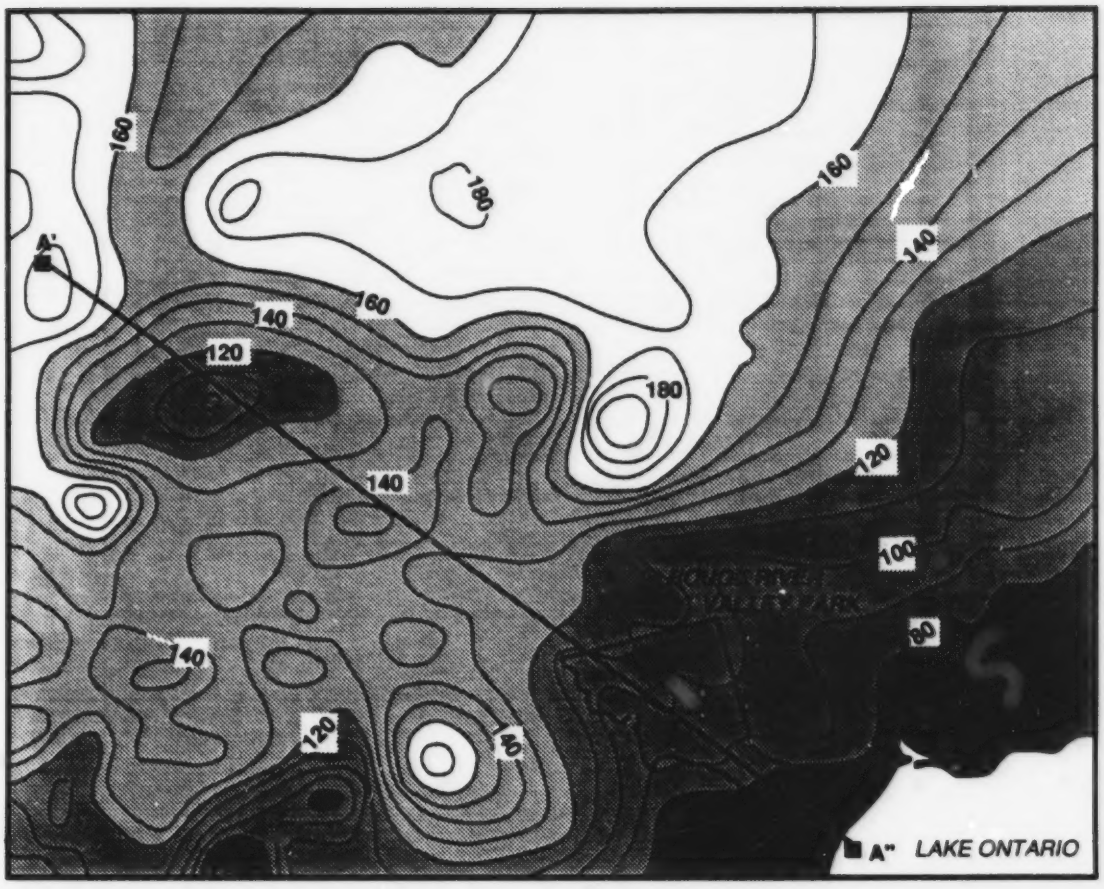


Figure 2.3 Groundwater flow within shale bedrock in northeastern part of study area (after Dillon 1988).



ELEVATION m a.s.l.

> 160

120 - 160

80 - 120

< 80

N

0 5 10

km

CONTOUR INTERVAL 10 m

A' A"

LOCATION OF REGIONAL GEOLOGIC CROSS-SECTION (Fig. 2.5)

Figure 2.4 Bedrock topography of the Rouge River drainage basin (after Sibul 1977).

To the south of the moraine, surface contaminants are introduced to groundwater via permeable zones or 'hydraulic windows' in the dense Halton Till. This is well documented in site investigations at a number of closed and existing landfills resting on the Halton Till in which leachate plumes have developed and are moving away from the sites in sub-till aquifers (e.g. Proulx and Farvolden 1990). For example, contaminants from the Beare Road landfill site (1969-1985) on the eastern park boundary have been detected in boreholes at greater than 30 m depth and some leakage to the Rouge River is suspected (e.g. Fig 2.3; Sobansky and Nunan 1981). There are, however, few data available and the detailed pattern of groundwater movement in the vicinity of the site, its relation to surface waters, and its impact on aquatic habitats are poorly understood.

The annual application of many tonnes of road salt to roads and highways that cross the park (e.g. Twyn Rivers Drive, Kingston Road, Highway 401) is known to have a local impact on surface and groundwater quality but insufficient background data are available. The problem is likely to be exacerbated by the planned 10 lane Highway 407 which will span the Rouge watercourses north of the park boundary and by the widening of Highway 401 across the lower Rouge River.

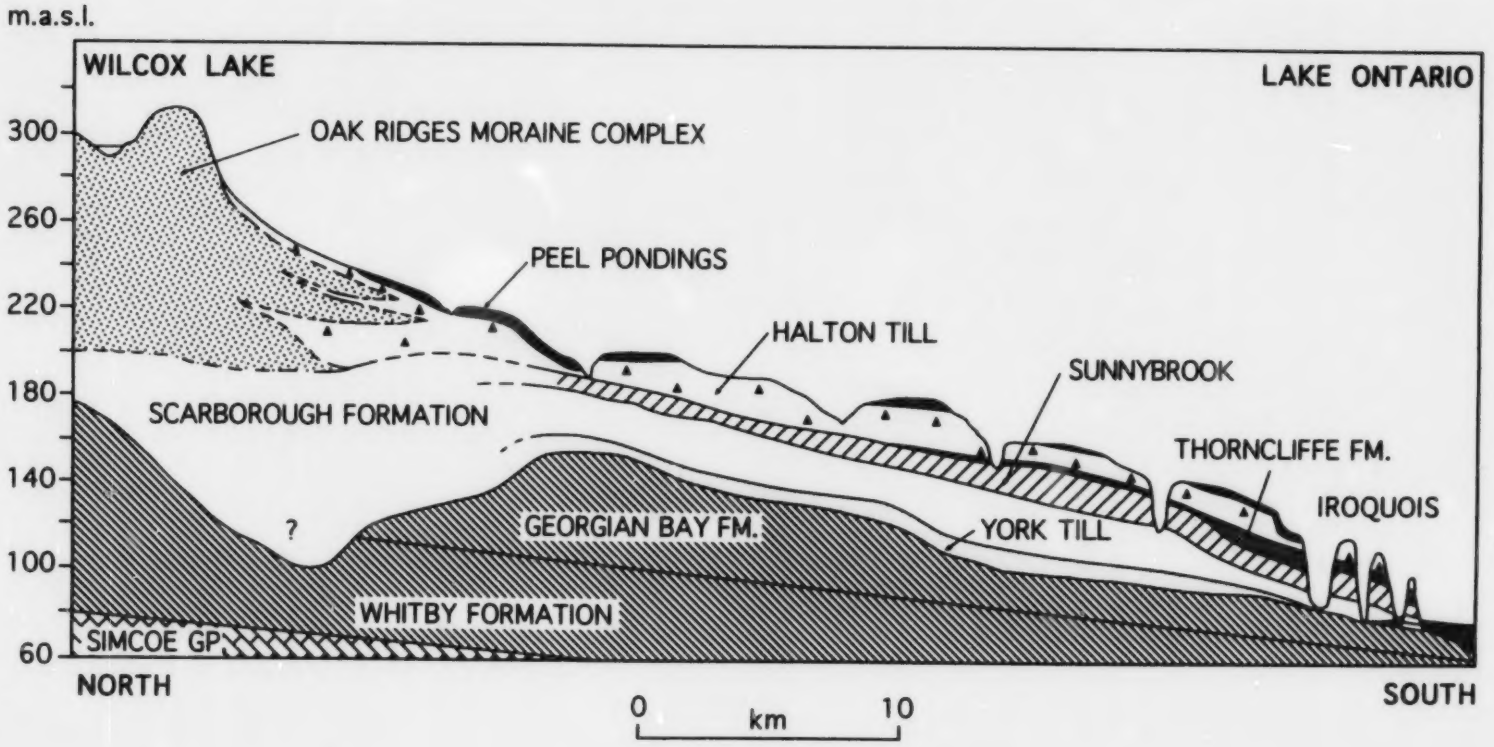


Figure 2.5 Schematic cross-section (NW-SE) through bedrock and Quaternary infill of Rouge drainage basin reconstructed on basis of water well records and MOE test well data. Location of line A'- A" is shown in Fig. 2.4 and 1.8.

2.3 Geology of the Rouge River Drainage Basin

The progressive downcutting of the Rouge River and Little Rouge Creek during the postglacial has exposed extensive sections through Paleozoic bedrock and the overlying Quaternary strata of the park area. These exposures provide a 'window' into the subsurface beneath the study area, and yield important information regarding the park stratigraphy and its geologic development. The bedrock and Quaternary geology of the park is discussed in the following sections with reference to a schematic geologic cross section through the basin (Fig. 2.5) and a map of the study area's surficial geology (Map 2).

The park's bedrock exposures were described originally by Parks (1927), who catalogued their fossil assemblages, and were most recently mapped by Liberty (1969) in a survey of the Paleozoic geology of the region. Bedrock is exposed intermittently in cut bank sections along a 2 km stretch of the Rouge River and Little Rouge Creek south of Twyn Rivers.

Stream outcrops of Quaternary sediments are best developed along an 8 km segment of the Rouge River between Finch Avenue and Twyn Rivers Drive (Map 3), where it deeply incises (up to 35 m depth) the Quaternary infill. A smaller number of exposures occur along the Little Rouge Creek which has not downcut its bed so deeply. Significant exposures also occur on the adjacent valley sides where bluffs are retreating due to slope erosion. A number of the stream sections within the park have been described previously by Karrow (1967) in his report on the Pleistocene geology of the Scarborough area, and by Clark (1986). The surficial geology of the park has been mapped in part by Westgate (1978) and Sharpe (1980).

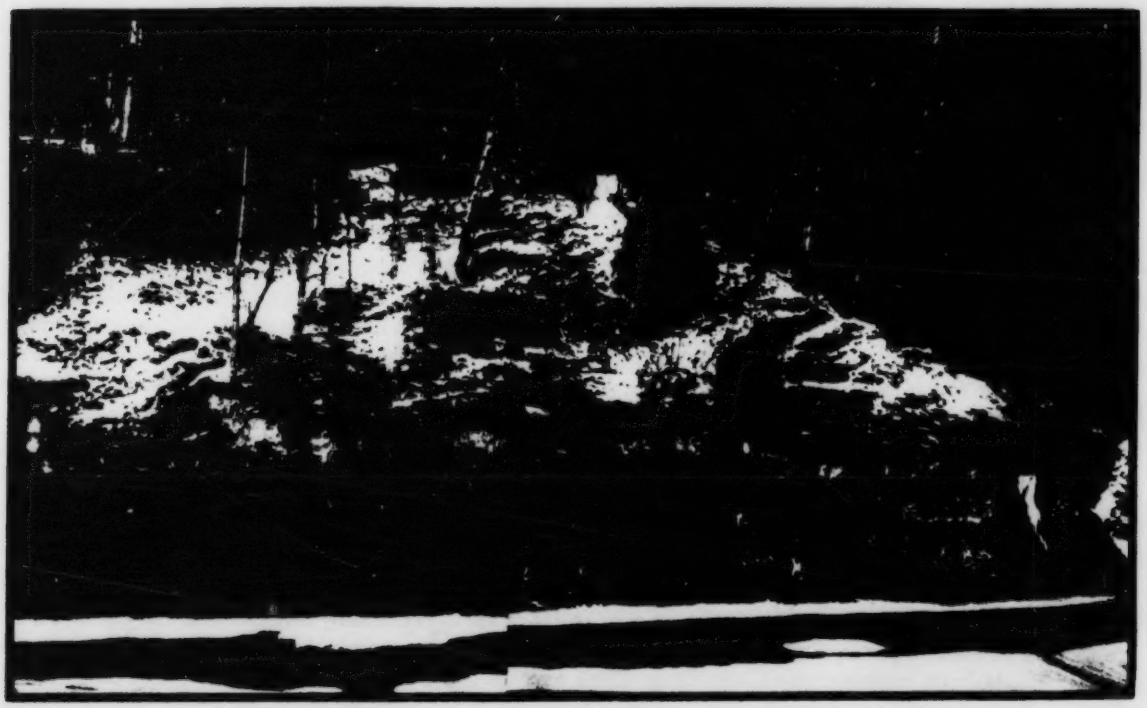
2.3.1 Paleozoic Geology

In the study area, bedrock comprises brown and grey-blue shales of the Upper Ordovician Whitby Formation (Fig. 1.4). These strata outcrop intermittently along the streambeds and banks of the Rouge River and Little Rouge Creek between Twyn Rivers Drive and the confluence point of the streams 3.5 km downstream (Map 2). Elsewhere, the shales are covered by thick Quaternary sediments. The bedrock surface in the vicinity of the park rises to the northwest from 60 m a.s.l. near the Lake Ontario shoreline to about 110 m a.s.l. at the park's northern boundary (Fig. 2.4). The courses of the Rouge River and Little Rouge Creek follow broad (1-3 km wide) northwest-southeast trending valleys eroded in shale bedrock which represent the most eastern tributaries of the Laurentian Channel system.

There are two principal localities in the park where the Whitby Formation is well exposed (Map 3): on the western bank of the Rouge River (R 23) 1.2 km downstream of the Twyn Rivers Bridge, and along the northeastern side of the Little Rouge Creek (LR 15) some 450 m downstream of the Twyn Rivers Drive crossing. Both the upper and middle members of the Whitby Formation are exposed at the Rouge section while only the upper member is represented at the Little Rouge locality. Both bedrock outcrops form a vertical face above river level and are relatively difficult to reach; limited access to the Little Rouge section can be gained via a small stream which intersects the outcrop midway along its length. Other very restricted bedrock outcrops are exposed on the western side of the Little Rouge Creek just above the confluence with the Rouge River.

The 1.5 m high outcrop on the Rouge River (Fig. 2.6.A) exposes at river level the brown and black fossiliferous shales of the middle Whitby member. These show a well-developed fissility and contain minor thin carbonaceous and petroliferous shale partings. Mud cracks and ripples are commonly observed where bedding plane surfaces are exposed. The Rouge River section is a site of provincial significance since it is the **type locality** for the middle Whitby member (Liberty 1969; formerly the Rouge River Formation of Liberty 1955). The middle member grades transitionally upward into blue-gray shales of the upper Whitby member near the top of the section. The latter is principally a clay shale which contains minor amounts of brown bituminous and calcareous shale. The bedrock section on the Little Rouge Creek exposes about 2.4 m of the upper Whitby Formation (Fig. 2.6.B). A number of other minor bedrock outcrops occur at various locations along the Rouge and Little Rouge south of Twyn Rivers Drive (e.g. Map 3; R023, LR016, LR018). These are generally less than 1 m in height and are poorly exposed due to riverbank slumping.

Figure 2.6 A. 1.5 m section exposing Middle and Upper members of Whitby Formation along Rouge River 1 km downstream of Twyn Rivers Drive. Outcrop is type locality for middle Whitby member. (Section R023, Maps 3, 4)



B. 2.4 m vertical section exposing upper Whitby member on Little Rouge Creek 400 m southeast of Twyn Rivers Drive. (Section LR015; Maps 3, 4)

The middle Whitby member is moderately fossiliferous and is correlated paleontologically with the Billings Formation in Ottawa and the Sheguiandah beds on Manitoulin island (Liberty 1969). The faunal assemblage is considered to be of Gloucester age (Liberty 1969) and includes abundant orthocone cephalopods (*Geisonoceras*), graptolites (*Diplograptus, Climacograptus*), fragments of trilobite (*Triarthus*) carapaces (mainly cranidia), pelecypods (*Cycloceras*) and a number of other invertebrate fossils. The locality is of considerable importance as it is the **type locality** for the trilobite *Triarthus rougensis* and the graptolite *Climacograptus rougensis*. A full faunal list for the Whitby Formation has been compiled by Liberty (1969).

The upper Whitby member is largely barren of fauna except for occasional, thin fossil-rich horizons. These contain an assemblage considered to be a Blue Mountain fauna correlative with the Sheguiandah beds on Manitoulin Island (Liberty 1969). The assemblage includes two varieties of graptolites (*Mastigograptus, Diplograptus*), and the trilobite *Triarthurthus hugensis*.

The Whitby Formation is interpreted as a marine shale deposited in an shallow, equatorial sea which inundated the eastern continental interior of North America about 450 million years ago (Fig. 1.3, A). This epicontiental sea occupied the vast Appalachian basin (Fig. 1.6) which formed as a result of downwarping of the eastern continental margin under the weight of the rising Taconic mountains (Brett and Brookfield 1984). The middle member records declining sea levels following the deposition of black, pyritized shales (lower Whitby member) in deep water. The presence of mud cracks and wave ripples in the middle member indicate deposition in shallow, marginal waters. The abundance of broken, disarticulated trilobite remains within these shales possibly records reworking by bottom current activity. Shallow conditions persisted during the deposition of the upper Whitby member; the presence of thin calcareous horizons and trilobite remains with limbs and thoraces intact (Liberty 1969) suggests quiet sedimentation, possibly in a shallow, lagoonal setting.

The Whitby shales at both localities show a well-developed orthogonal joint system consisting of near vertical, first order joints oriented west-east associated with a second set striking north-south. The first order joints are sharply defined and are spaced at approximately 0.3 to 1 m intervals across the outcrops (Fig 2.7). Large-scale faults present in overlying Quaternary strata show similar west-east trends and may record the propagation of tectonic stresses upward from bedrock as a result of earthquake activity during the late Quaternary (Mohajer and Eyles 1991; Chapter 2.3.2).

2.3.2 Quaternary Geology

A thick sequence of Quaternary sediments was deposited over the Ordovician bedrock of the study area during a succession of glacial and non-glacial periods over the last 150,000 years. This sequence of strata represents the eastern part of the Laurentian Channel infill which is exposed to greatest depth at the Scarborough Bluffs. The study area is situated further eastward, at the margin of the channel (Fig. 1.9) and, as a result, the sequence preserved here is only one third as thick as the Bluffs succession.

Most of these representative Late Quaternary units are represented within the study area and are shown schematically in Figure 2.5 and summarized in Appendix C. The depositional history of these sediments has been outlined previously in the introduction (Chapter 1.3); discussion in the following sections will focus on the distribution and identifying characteristics of the Quaternary strata exposed in the park area.

The Quaternary infill generally thins toward the southeast along the axis of the Rouge basin as a whole, from greater than 180 m where the Oak Ridges moraine and older glaciolacustrine strata rest within the Laurentian Channel, to less than 20 m near the Lake Ontario shoreline (Fig. 2.5). Glacial episodes are recorded by poorly-sorted and over-consolidated sediments (tills) deposited by ice sheets that covered much of the Great Lakes area. Non-glacial intervals are represented by lacustrine and fluvial sediments.

York Till

The oldest Quaternary unit in the Greater Metropolitan Toronto area is the York Till (Terasmae 1960). This till records an ice advance into the Ontario basin, sometime prior to 125,000 years ago, and has been assigned tentatively to the Illinoian Glaciation (Appendix C).

The only outcrop of the York Till in the study area occurs along the northern bank of the Little Rouge Creek about 200 m northwest of Kingston Road (Map 3, LR 19). The York Till is represented here by 2 m of buff brown, clayey sand till exposed at river level. The till contains mainly shale fragments (*ca.* 75%) derived from the underlying Whitby shales and lesser amounts (22% and 3% respectively) of limestone and Precambrian materials (Karrow 1967). Grain size analyses of the till indicate that on average it contains 54% sand, 24% clay and 22% silt (Ostry 1962; Karrow 1967).

At present the outcrop is largely obscured by sands slumped from the overlying Scarborough Formation. The till has not yet been identified in the subsurface in the park area but is commonly exposed by construction activity in downtown Toronto and is inferred to overlie bedrock across the region (Eyles 1987a).

The York Till is overlain regionally by the Don Beds (Chapter 1.3), a warm climate sequence of clays and sands deposited along the margins of an ancestral Lake Ontario. Climatic conditions at this time were similar to, if not warmer than, those of the present day. Outcrops of the Don Beds are restricted to the Don Valley (Terasmae 1960; Karrow 1967; Eyles and Clark 1987) and are not present, or at least do not outcrop within the Rouge park area. These units were identified in the subsurface below the Beare Road landfill site by Sobansky and Nunan (1981).

Don Beds

Recent erosion by the Rouge River has exposed a new outcrop of the Don Beds (Section R022; Fig. 2.7). These sediments have been extensively studied at the Don Valley brickyard site near downtown Toronto, and represent the most detailed record of the last interglacial period known in eastern North America. The Don Valley Brickyard outcrop is an internationally-recognized type section and has been visited and admired by hundreds of geologists since its discovery in the late nineteenth century. A.P. Coleman who first described the site, was the first Professor of the then new science of Geology at the University of Toronto and in 1926 declared the Don Valley Brickyard site as 'one of the geological gems of the world'. The site is now badly exposed and faces an uncertain future. The discovery of a new section along the Rouge Valley is of great significance.

The Rouge Valley outcrop matches 'bed-for-bed' the stratigraphy exposed in the brickyard (see above, Chapter 1.3) with the exception that the Rouge Valley site is of reduced thickness (1.75 m). Detailed geological studies are needed to determine the fossil record and to reconstruct the local environment found along the Rouge River Valley some 125,000 years ago. The outcrop is deformed by neotectonic faulting (Fig. 2.7) with the same strike orientation as at section R020 to the north (Fig. 2.8).

Scarborough Formation

Above the York Till is a thick (up to 80 m), coarsening-upwards succession of clays, silts and sands deposited in a delta (Scarborough Formation; Table 1). This sequence records a climatic deterioration and rising water levels in ancestral Lake Ontario which accompanied early phases of the last (Wisconsinan) glaciation. The Scarborough Formation comprises a continuous sequence of sedimentation but is traditionally divided into a lower member consisting of laminated silts and clays (Scarborough clays) and an upper sandy member (Scarborough sands). These are well exposed at the Scarborough Bluffs where they have a combined thickness of over 40 m. The sandy upper part of the Scarborough Formation comprises a regionally extensive aquifer within the Quaternary infill of the Laurentian Channel (Kelly and Martini 1986; Eyles *et al.* 1985a; Eyles 1987a).

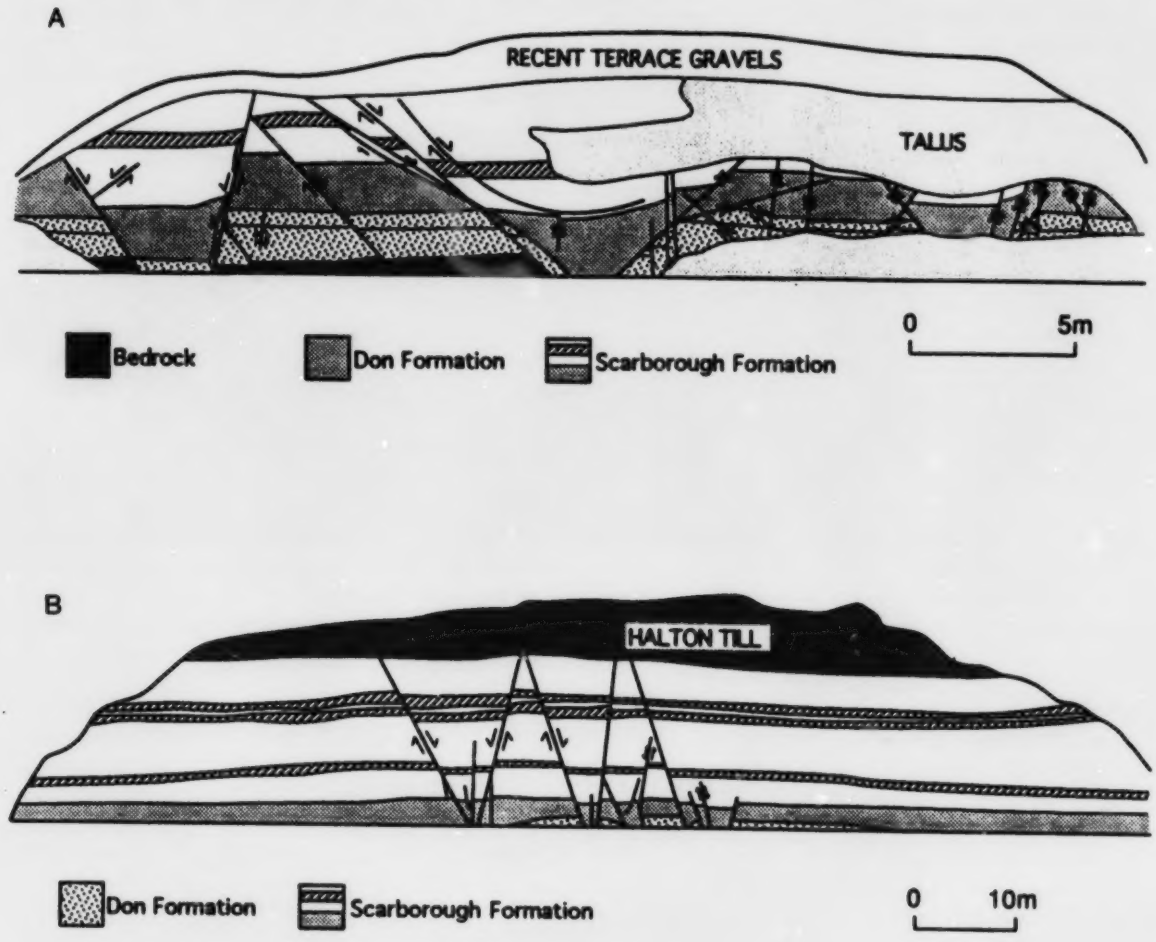


Figure 2.7 A. Quaternary and bedrock section (R022) exposing faulted Whitby Formation shales, Interglacial Don Beds and Scarborough Formation on Rouge River south of Twyn Rivers Drive.

B. Faulted Scarborough Formation sediments north of Twyn Rivers Drive (Section R020) 250 m north of section R022.

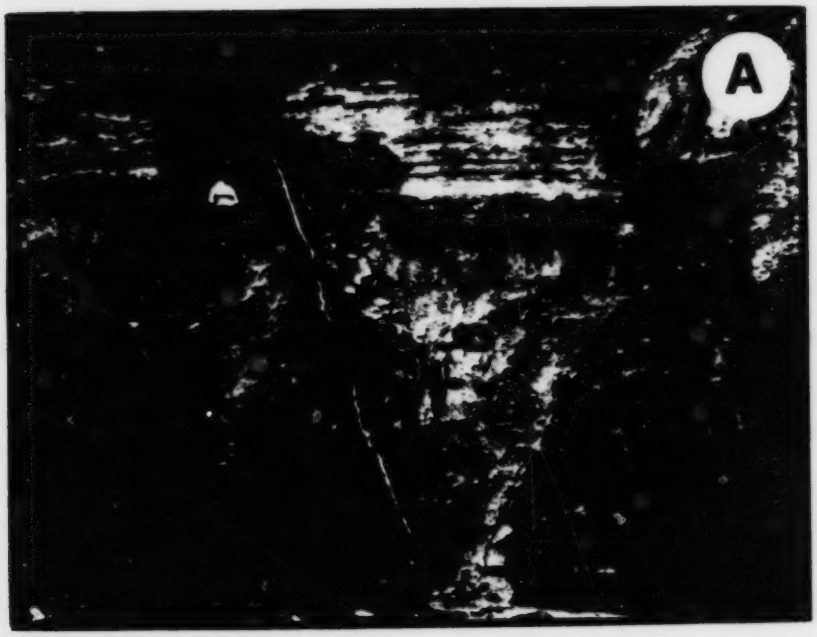
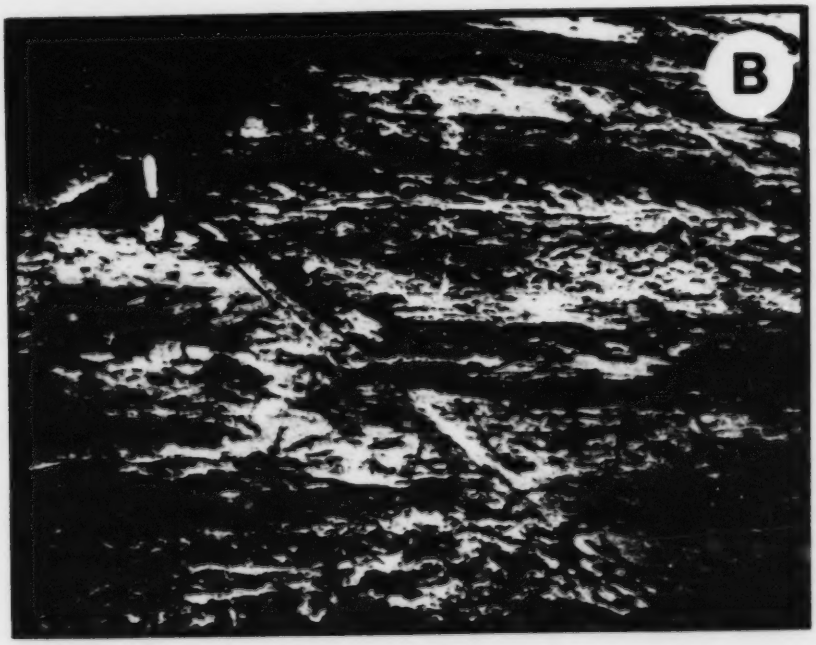


Figure 2.8 **A.** Fault (indicated by white line) propagated from bedrock through Scarborough Formation on northeast bank of Rouge River, 100 m northwest of Twyn Rivers Bailey bridge (outcrop locality R020).



B. Detail of upper 1.5 m of fault showing offset sand and laminated silt beds (arrows indicate direction of slip).

Scarborough Formation sediments are exposed along the Rouge River in the vicinity of Twyn Rivers Drive (Map 3). The best exposure of the Scarborough Formation within the study area occurs in a 30 m high, cut bank exposure on the east side of the Rouge River (Figs. 2.7, 2.9) immediately northwest of the Twyn Rivers Drive (Map 3, R020). At river level, the outcrop consists of 4 m of dark grey, rhythmically laminated, silty clays (Scarborough clays) which grade transitionally upward into fine, variably bedded silts and, finally, into massive silty-fine orange sands in beds up to 1 m in thickness (Scarborough sands).

Rhythmites consist of silt and clay laminations up to 2 cm in thickness and have been interpreted as 'varves' (Coleman 1933) recording the annual waxing and waning of sediment input in a seasonally influenced lake. These contain variable amounts of organic matter (0.01 to 0.35%) consisting mainly of detrital peats and other plant fragments (see Chapter 1.3). Siderite (iron carbonate) concretions are also commonly observed and occur as thin, platy inclusions.

The overlying sands show a variety of bedding, dominated by planar and trough-cross bedded, horizontally laminated and rippled sands. Planar crossbeds may be up to 1 m thick and have foresets which consistently indicate paleocurrents towards the south. Bedding surfaces are often sharply demarcated by heavy mineral concentrations which consist mainly of magnetite and garnet, and by abundant detrital peat layers. The Scarborough sands are typically a dark orange colour due to an abundance of iron oxides which allows them to be distinguished from the more buff and grey coloured sands of the younger Thorncliffe Formation and Lake Iroquois.

It has been recently observed that the orientation of first order joints in bedrock is striking similar to west-east trending, high angle faults present in the Scarborough Formation (Daniels 1990; Mohajer and Eyles 1991) where it is exposed north of Twyn Rivers Drive at section R020 (Map 3). At this locality, southwestward dipping (60°) faults with vertical offsets of up to 1.25 m penetrate the Scarborough clays (Fig. 2.8). These are truncated by the overlying Halton Till (Fig. 2.9) and have no known surface expression.

The faults are associated with abundant soft sediment deformation structures such as folded and faulted laminae, and sand dykes up to 30 cm in width injected along fault planes. Mohajer and Eyles (1991) suggest that these features are characteristic of liquefaction of saturated sediments as a result of ground shaking during a large-magnitude earthquake (e.g. Tuttle *et al.* 1990). They propose that the faults and associated liquefaction phenomena record significant earthquake activity in the region, occurring sometime after the deposition of the Scarborough clays (between *ca.* 80,000 to 13,000 B.P.).

There is intense international discussion concerning the regional significance of these joints and faults especially in relation to the seismic hazard assessment for incorporation into the 1995 National Building Code of Canada and for risk evaluation for nuclear facilities in southern Ontario. The well exposed bedrock and Quaternary outcrops of the study area are currently the focus of regional seismic hazard investigations by government and university groups (Rogojina *et al.* 1992).

The Scarborough Formation contains a wide diversity of floral and faunal remains including over 60 plant species, 10 species of molluscs, and over 70 insect varieties (Appendix A). Studies of the vertical succession of pollen (Terasmae 1960), larval caddisfly, and chironomid beetle taxa (Morgan 1972; Williams *et al.* 1981) within the Scarborough Formation indicate a marked cooling trend culminating near the top of the sequence in a cool, boreal climate with mean annual temperatures 2 to 5°C less than present.

Figure 2.9 a. Scarborough Formation (Sc) overlain by Halton Till (H) and Iroquois sands (Ir) at section R 20; same locality as Fig. 2.8.

Sunnybrook Till

The Sunnybrook Till is the next youngest stratigraphic unit (Appendix C) and records the earliest Wisconsinan ice advance into the area (Eyles and Eyles 1983; Dreimanis 1984; Eyles *et al.* 1987, and references therein; Rutka and Eyles 1989). The Sunnybrook crops out extensively along both rivers for about 3.5 km northwest of Meadowvale Road and is best exposed within the entrenched meander west of Reesor Road (Map 3, R 7, R 8). Between Meadowvale Road and just southeast of Twyn Rivers Drive the Sunnybrook has been completely eroded by the Halton Till which rests directly on the Scarborough Formation (Map 2). In other exposures, the Sunnybrook Till is relatively resistant to erosion and tends to form free-standing vertical faces above river level.

The Sunnybrook Till comprises 5 to 10 m of distinctive dark grey, fine-grained, clayey-silt till which rests conformably on the Scarborough delta throughout the park area (Fig. 2.5). It is typically a dense, massive pebble-poor silty-clay which contains stratified horizons consisting of silt and clay rhythmites. Mechanical analyses (Karrow 1967) yield an average composition of 45% clay, 37% silt, and 18% sand. The unit has a distinctive 'blocky' appearance due to the presence of well developed orthogonal jointing. The retreat of bluffs formed in the Sunnybrook Till tends to occur by slab failure along these joint surfaces, resulting in the maintenance of a relatively vertical face (Eyles *et al.* 1985b).

The Sunnybrook contains a low diversity ostracode fauna (bottom dwelling arthropods) consisting of *Candona subtriangulata*, *Candona caudata* and *Darwinula stevensoni* (Westgate *et al.* 1987; Rutka and Eyles 1989). These species inhabit the bottom sediments of freshwater lakes and are widely reported from modern and Pleistocene lacustrine sediments. The sub-macroscopic calcareous shells of these organisms are very fragile and

generally require quiet sedimentation conditions for preservation (i.e. lake bottom). The presence of such an *in situ* fauna in the Sunnybrook Till has been cited as indicating its origin as a glaciolacustrine pebbly mud (Westgate and Eyles 1987; Rutka and Eyles 1989) rather than as a till deposited directly beneath an ice sheet (Dreimanis 1977; Fullerton 1986).

The ostracodes in the Sunnybrook and associated sediments provide important data regarding the late Quaternary history of Toronto and the study area. The shells of individual ostracodes contain a record of the proportion of two stable isotopes of oxygen ($^{18}O/^{16}O$) present in the water at the time the organism was living. This proportion varies according to regional changes in temperature, allowing determination of the paleoclimate; the technique (oxygen isotope analysis) has been used on deep ocean sediments where there is a continuous record of sedimentation during the last several million years. Figure 2.10 shows what has been termed the 'Rosetta Stone' of paleoclimate investigations, the oxygen isotopic record of global climate over the last 700,000. These data show alternating ice ages and interglacials and were derived from marine microfauna preserved in bottom sediments obtained from the ocean floors.

The glacial/interglacial cycle has a periodicity of about 100,000 years and is controlled by variations in the Earth's orbital parameters (*tilt*, *precession* and *eccentricity*; the so-called 'Milankovich Variables' after the Serbian mathematician who first recognized them). The periodic nature of glacial/interglacial cycles allows future ice ages to be predicted and provides a 'yard stick' against which to measure man-made changes in climate (e.g. the 'Greenhouse Effect').

The record derived from ostracods present in the deposits of the Toronto region (Fig. 2.11) allows paleoclimate reconstruction for the last 70,000 years, and parallels and confirms that seen on a global scale. This is of particular interest to the geological community and is one of the first examples where a correlation between the North American continent and the ocean oxygen isotopic record has been established (Eyles and Schwarcz 1991; Schwarcz and Eyles 1991).

Thorncliffe Formation

Overlying the Sunnybrook Till is the Thorncliffe Formation, a sequence of deltaic sand and silts (Karrow, 1967; Eyles and Clarke, 1987) which record high-level lakes associated with regional ice retreat and the development of glaciolacustrine environments during the middle part of the Wisconsinan glaciation. Within the park, the Thorncliffe Formation has an average thickness of about 5 m and is best exposed along the entrenched segment of the Rouge River in the vicinity of Old Finch Avenue (Map 3, R 6; Fig. 2.12). The only known Thorncliffe exposure on the Little Rouge Creek occurs 400 m east of the Meadowvale Road underpass (Map 3, LR 12).

The Thorncliffe Formation comprises thin-bedded silts and clays which alternate repeatedly with deltaic and channelized fluvial sands. Silts and clays are rhythmically laminated (rhythmites) and have been interpreted as varved sediments (Antevs 1928). Sands are fine-grained, buff brown to grey in colour, and are variably cross-bedded or occur as massive beds up to 1 m in thickness. Sands are generally more abundant than silts and clays and comprise important regional aquifers. Numerous seeps and springs can be observed (Fig. 2.13) where the Thorncliffe outcrops over the relatively impermeable Sunnybrook Till west of Reesor Road (Map 3; R 7, R 8). Minor clayey-silt till units (the Seminary and Meadowcliffe Tills) occur within the Thorncliffe Formation in the area of the Scarborough Bluffs (Karrow 1967; Eyles 1987a) but are absent, or at least do not outcrop in the study area.

The Thorncliffe Formation is generally unfossiliferous other than occasional detrital peat layers and some pollen. Analysis of pollen assemblages indicate cold boreal conditions analogous to the climate which existed during deposition of the Scarborough Formation (Karrow 1967).

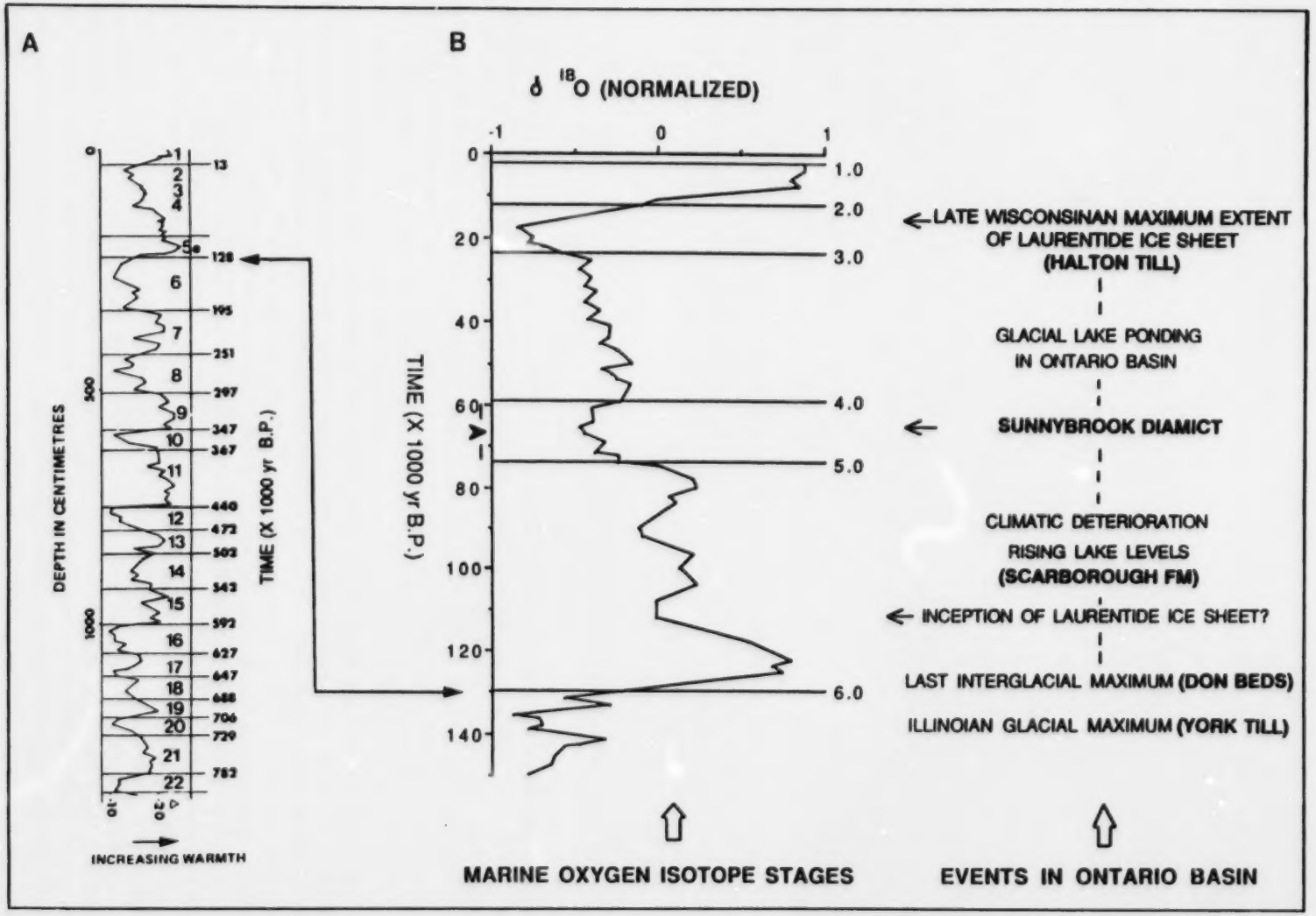


Figure 2.10 A. Oxygen isotope record of last 700,000 years obtained from Pacific Ocean ('Rosetta Stone' of paleoclimate studies).

B. Last 130,000 years of marine oxygen isotope record shown in relation to events in the Ontario basin (after Eyles and Westgate 1987).

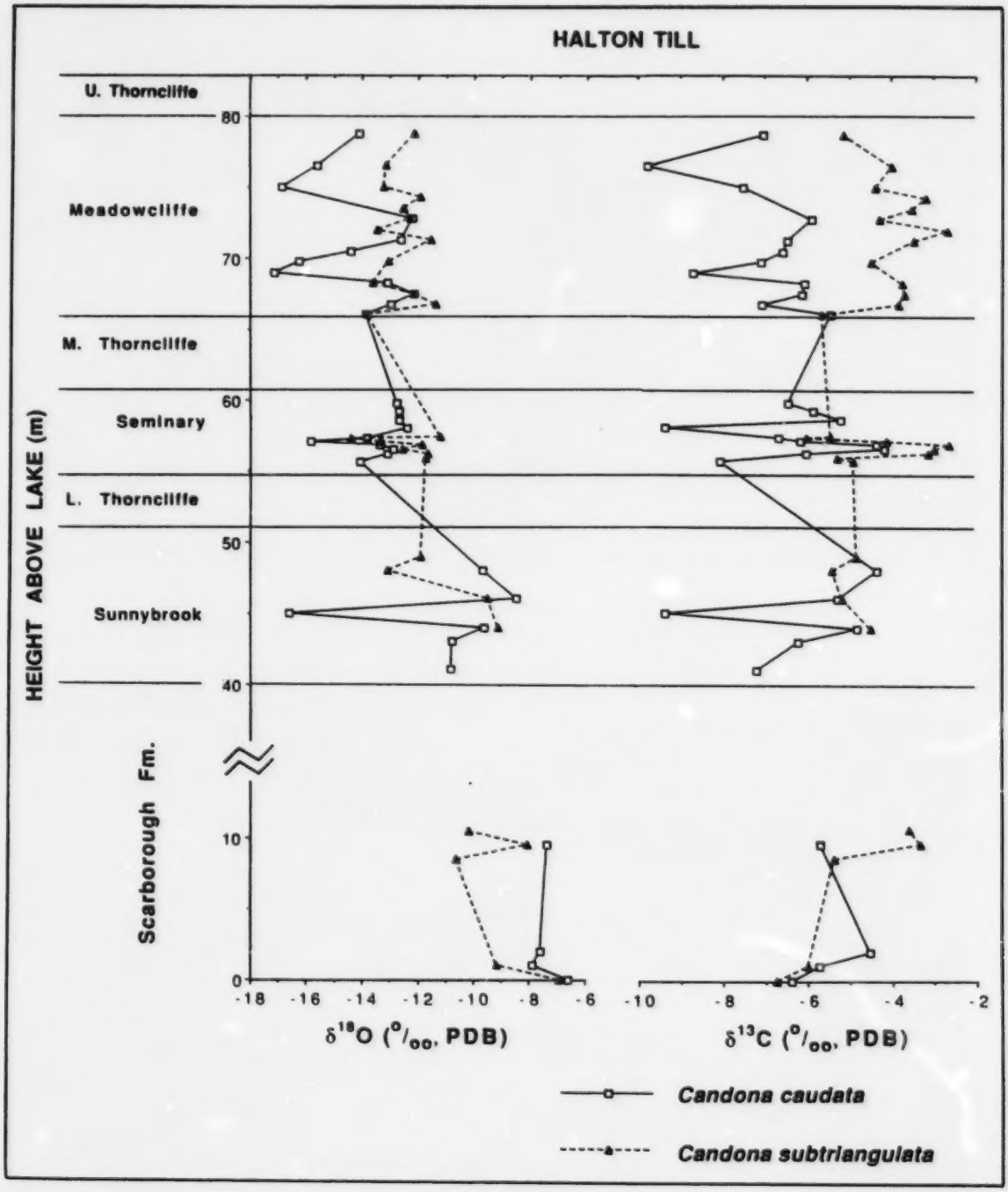


Figure 2.11 Oxygen isotope record of last 70,000 years in North America obtained from ostracodes present in Quaternary sediments of Toronto area (from Eyles and Schwarcz 1991; compare with Fig. 2.10).

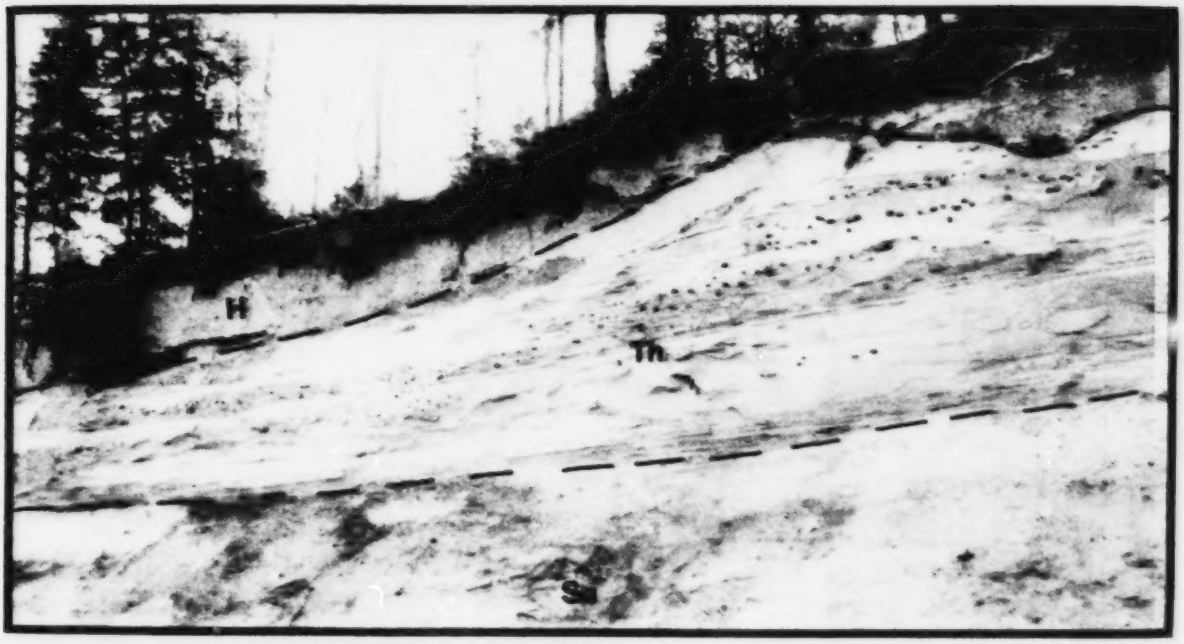


Figure 2.12 Horizontally bedded sands of Thorncliffe Formation (Th) well exposed at section R 6 on the Rouge River near Finch Avenue. Sands overlie Sunnybrook Till (Su) and are erosively truncated by Halton Till (H) and stream terrace gravels (ST).

Figure 2.13 Section R 7 showing Sunnybrook Till (Su) overlain by thin Thorncliffe sands (Th) capped by Halton Till (H). Note development of piping and caving of sands due to groundwater sapping along contact between sands and till.

Halton Till

The Halton Till (Table 1) is the dominant surficial Quaternary unit across the Greater Metropolitan Toronto area, and the youngest glacial unit in the Rouge park area. Formerly known as the Leaside Till (Karrow 1974), the Halton Till was deposited subglacially beneath the Lake Ontario lobe of the Laurentide Ice Sheet, about 13,000 years ago (Fig. 1.3E). This unit can be tens of metres thick and cuts unconformably across older sediments. In the study area, it rests on Early to Mid-Wisconsinan glaciolacustrine sediments and is widely exposed in bluffs along the Rouge River and Little Rouge Creek. The till is best exposed in a 40 m bluff on the northeastern side of the Rouge River (Map 3, R015) in the vicinity of the Metropolitan Toronto Zoo. At this locality the Halton and Sunnybrook tills have been eroded in to a series of scallops and pinnacles termed 'hoodos' (Chapter 2.4.2).

In contrast to the fine-grained, older Wisconsinan tills, the Halton Till is a sand-rich (>33%; Karrow 1967; Sibul *et al.* 1977; Brookfield *et al.* 1982) silty-sand to sandy-silt till. Typically, it is a very dense, overconsolidated deposit consisting of silt to boulder-size particles which have accumulated under pressure at the base of a moving glacier. The till contains abundant Paleozoic limestone pebbles and far-travelled granitic boulders transported south from the Canadian Shield. The till has a sharply erosive base and contains abundant sand and gravel pods and stringers derived by the inclusion of underlying deposits.

Deformation features occur within the till on a variety of scales, from thin friable sheared horizons millimetres in thickness to large drag folds up to 6 m in width. The depositional process at the base of the sliding glacier was one of continued mixing of and plastering of incorporated sediments against the substrate, resulting in the formation of an over-consolidated, dense till resembling concrete in appearance. The term 'raisin cake' texture has been used to describe its typical appearance in outcrop.

The Halton Till may also show local textural variability related to differences in substrates eroded by the ice and mixed during the transport and deposition of the sediment (Hibbert 1990). Thick, massive deposits of this type of till are common in glaciated areas which display a distinct drumlinized surface topography (Eyles 1983; Menzies and Rose 1987). The Halton Till also includes local lenses of washed gravel, sand or silt. These granular soils were deposited by meltwaters beneath the ice and along the ice margin and generally occur as discontinuous lenses within the till. The surface of the Halton Till is drumlinized and fluted; several good examples of these streamlined landforms occur on the tableland in the northern part of the Rouge park (Chapter 2.4.1).

In some parts of the tableland, the Halton Till is covered by younger soils including shallow deposits of lake and outwash sediments. These are generally less than a few metres in thickness, and were produced by meltstream activity and local ponding during ice retreat at the end of the last glaciation (Karrow 1967; Sibul *et al.* 1977).

Lake Iroquois Deposits

The end of the last glaciation is marked within the study area by lacustrine sediments of high-level Lake Iroquois, which extensively overlie the Halton Till south of the abandoned shoreline. In the vicinity of the shoreline, these consist of beach sands and gravels up to 5 m in thickness which give way to thin spreads of offshore sands and deep water silts and clays toward the south (Map 2).

The Iroquois beach deposits consist of up to 5 m of buff brown coloured, variably-bedded sands which are interstratified with shingled gravels and extensive boulder horizons. These deposits cap the tablelands between the Rouge and Little Rouge river valleys and are well exposed along the Rouge River and Little Rouge Creek for several hundred meters upstream of Twyn Rivers Drive (Map 3, R 19, R 20, LR 14). The beach gravels are typically well sorted and rounded and were derived largely by reworking of the Halton Till by wave action (Karrow 1967). The gravels have been comprehensively worked for aggregates throughout the study area so that most of the former beach is now made-ground with an irregular, hummocky surface topography.

The offshore deposits consist of thin (< 1 m) variably-bedded silty sands and laminated (varved) silty clays which drape and locally infill shallow depressions in the surface of the Halton Till plain to the south of the Iroquois beach zone. Owing to their restricted extent, these sediments are not well exposed within the park area.

The Lake Iroquois sediments generally contain little fossil material other than some mollusc remains found at a few restricted localities (Karrow 1967).

Recent Stream Deposits

The most recent deposits in the park area are alluvial silts, sands and bouldery gravels (Alluvium; Appendix C) deposited along the streambeds and floodplains of the Rouge River and Little Rouge Creek during the Holocene (10,000 B.P. to present). These deposits can be subdivided into recent stream sediments occupying the present floodplain, and older terraced deposits which record earlier, higher-level river stages.

The recent floodplain deposits consist of sands and bouldery gravels deposited along the streambeds and horizontally bedded, 'overbank' fine sand and silt accumulated during episodic flood events. Bouldery stream gravels form the riverbeds principally along the river segments between Twyn Rivers Drive and Finch Avenue, where they are derived by reworking of the Halton Till and Iroquois beach deposits. In the lower reaches of the rivers, the floodplains are constructed dominantly of fine alluvial silt and sand.

Cut banks along the Rouge and Little Rouge valleys show many sections cut through the stratigraphy of the recent floodplain. These outcrops show beds of laminated and rippled sands up to 50 cm thick separated by buried soils and mats of peat and organic debris such as tree limbs (Fig. 2.14). The sands are 'overbank' deposits laid down during major flood events when the river overtops its channel. The soils, peat and organic debris records the burial of vegetation by sand. Newly deposited sand sheets are in turn recolonized by vegetation only to be buried by the next flood event. Buried soils along the Rouge Valley system have been investigated by Mahaney and Sanmugadas (1986) and Mahaney *et al.* (1991).

These sediments are best exposed in up to 2 m high cut bank sections south of Twyn Rivers Drive (e.g. Map 3, R 25, LR 17). A well exposed section on the Rouge River at locality R 25 shows 2 m of horizontally-bedded fine sand and silt which contain thin organic and rooted horizons (Fig. 2.14).

Older alluvium is preserved in abandoned terraces at several localities along both rivers (e.g. Map 3, R 18, LR 4, LR 3) and typically comprises crude, fining-upwards sequences of up to 2 m of bouldery gravel and sand overlain by stratified, silty sand. Such sequences record the migration of river channels with the deposition of overbank fines over coarse stream bed materials. These deposits are often difficult to distinguish from the bouldery sands and gravels of Lake Iroquois which frequently cap the Quaternary sequence south of the abandoned shoreline. The alluvial deposits are generally identified by their higher boulder contents and more restricted lateral extent when compared to Lake Iroquois sediments.

Figure 2.14 Cut-bank exposure on lower Rouge River at section R 25 showing 2 m of horizontally bedded overbank fine sands and silts. Each bed is separated by peat and records a flood event.

2.4 Landforms and Geomorphic Features

The present park landscape is the result of a variety of Quaternary geomorphic processes occurring in the glacial, lacustrine, fluvial and associated environments that have affected the area during the past 130,000 years. The effects of the last Wisconsinan glaciation have been most dominant, and have produced a suite of landforms and associated features (*glacial assemblage*) which record the growth and decay of the Laurentide Ice Sheet and the development of extensive glacial lakes in the Ontario basin. Landscape change during the postglacial period, after about 12,000 B.P. (Appendix C), has been less extensive, involving mainly the modification of the emergent glacial landscape by fluvial, lacustrine and subaerial processes. Nevertheless, the resultant features (*postglacial assemblage*) are distinctive and have contributed to the continually changing park landscape. Finally, man-made changes to the landscape associated with urbanization and mining of aggregates have been profound and are ongoing.

2.4.1 Glacial Assemblage

Subglacial Features

The landscape of the park area is dominantly of glacial origin and was shaped during a final excursion of Late Wisconsinan ice (Ontario lobe) out of the lake basin to the northwest, shortly after 13,000 B.P. (Fig. 1.3E). The ice lobe advanced some 50 km northward of the present Lake Ontario shoreline to abut against an west-east trending topographic divide comprising the early Oak Ridges moraine. During its occupancy of the region (*ca.* 1000 years), the ice completely remoulded and reworked the land surface, removing or burying beneath a thick sequence of sediment, any vestiges of the pre-existing landscape. Erosional and depositional processes at the base of the ice sheet resulted in progressive reduction of the surface topography and the formation of an extensive, low-relief till plain across the region (the Halton Till plain of Chapman and Putnam 1984). The Halton Till plain is represented in the park area by some 15 km^2 of gently undulating, glacially streamlined terrain lying to the north of Finch Avenue (Map 1).

Drumlins and flutes are the principal landforms on the Halton Till plain and record the movement of grounded ice across the region. Drumlins are classically described (e.g. Flint 1957) as elongate hills, which in profile have a blunt up-ice end (stoss), and gently sloping tail (lee) which tapers off in a down-ice direction. Flutes are positive, linear ridges which are elongated parallel to ice flow and separated by shallow troughs in the till plain. The degree of elongation of drumlins and flutes is usually measured by the ratio of their long and short axes; it is conventional to classify elongate ridges with axial ratios (L/W) greater than 10 as flutes or 'flute-like drumlins'. The long axes of drumlins and flutes are characteristically aligned with the last direction of ice flow. This has prompted their common usage in the reconstruction of the extent and movements of Pleistocene ice sheets.

A wide range of drumlin morphologies occur within the park area (Map 1) including poorly-defined, ellipsoidal hills or drumlinoids, moderately streamlined oval drumlins and highly extended drumlin forms which are transitional to flutes.

Most drumlins within the park and surrounding area are of the oval type, with length to width ratios which are in the range of 2 to 3. These drumlins are commonly between 300 to 1000 m in length, 10 to 30 m in height and are sparsely distributed, with less than 5 drumlins occurring in an area of 10 km^2. Owing to their low height and low level of development, these features appear as broad, rounded swells in the till plain surface when viewed from ground level. Delineation of their form requires reference to topographic maps and air photos. The best example of a low (< 10 m), ovoid drumlin form can be viewed to the northwest of Reesor Road 250 m north of its junction with Old Finch Avenue.

Crudely-formed drumlinoid hills dominate the till plain to the northeast of the park in the vicinity of Cherrywood (Map 1). These features are up to 1 km in length and 40 m in height and are roughly oblate to asymmetric in plan. Frequently, these are compound features consisting of a number of coalesced drumlinoid ridges. Narrow flutes (< 100 m width) are developed extensively across the surface of the drumlinoid hills.

Elongate, spindle-shaped drumlins with axial ratios (L/W) in excess of 5 occur at only two localities within the park: on the west side of the Little Rouge Creek, 1 km southeast of Steeles Avenue (550750/645550), and 100 m northwest of the junction between Old Finch Avenue and Reesor Road (530800/645450). The latter locality is of particular interest because the drumlin is dissected mid-length by a meander loop of the Rouge River. The stream section through the drumlin shows that it is composed of a core of undisturbed Early to Mid-Wisconsinan glaciolacustrine sediments (Sunnybrook Till and Thorncliffe Formation) truncated erosively by a mantle of Halton Till. This exposure importantly demonstrates that the materials forming the core of these drumlins pre-dates the drumlinization event; a finding which has implications for current ideas regarding the origin of these features (see below).

The spindle drumlin on the Little Rouge Creek is also of interest because its apparent direction of streamlining opposes the regional ice flow direction to the northwest. Such 'reversed' drumlins have been reported elsewhere in areas where ice flow patterns have been well established from a variety of other indicators (e.g. Peterborough drumlin field; Gravenor 1957). In general, very few drumlins in a given drumlin field show anomalous orientations (e.g., < 1%, Peterborough drumlin field; Boyce 1990). The phenomenon is not well understood but may be associated with areas of localized ice deceleration and flow.

Well developed flutes over 5 km in length and 200 m in width score the surface of the Halton Till plain (Map 1) and occur in such profusion that its surface has a 'corrugated appearance' in air photos. The flutes are generally less than 5 m in height and are separated by broad, parallel troughs which confine the paths of small contemporary streams draining the till plain. Exceptional examples of narrow, 2 to 5 m high flutes can be observed bearing-off to the southeast of Steeles Avenue, 400 m west of its junction with the Pickering Townline Road.

Flutings are cut across and superimposed on drumlins indicating that they were formed subsequent to drumlinization, during a final streamlining event. The general orientation of flutes and drumlins (Map 1) suggest a regional ice flow direction consistently to the northwest between 130° and 137°. Locally, the trends of flutes and host drumlins may vary by as much as 15° and record minor shifts in ice flow direction, probably as a result of localized topographic effects.

Many drumlins have been modified and extended into flute-like forms as a result of the latest stage of glacial streamlining. This is most evident in a flute-like drumlin which runs diagonally across the Pickering Townline Road about 1.3 km north of its junction with Finch Avenue. The flute extends some 1.2 km northwest of the CPR tracks where it draws-out part of an originally oval-shaped drumlin.

The origin of drumlins and flutes is currently a subject of intense debate among glacial geologists. Current models of drumlin formation emphasize either the erosional and depositional effects of catastrophic meltwater floods (meltwater hypothesis; Shaw 1983; Shaw and Kvill 1984; Shaw and Sharpe 1987) or the large-scale deformation of sediments beneath ice sheets (deformation hypothesis; Smalley and Unwin 1969; Bolton and Hindmarsh 1987; Boulton 1987).

The *meltwater hypothesis* attempts to relate drumlins to small-scale, fluvially-eroded, streamlined forms such as flutes (Allen 1969), and linear and crescentric scours (Shaw and Kvill 1984) on bedrock surfaces. According to the model, some drumlins represent positive moulds of subglacial cavities (e.g., Shaw 1983) scoured in the undersurface of the ice by large-magnitude floods which are subsequently infilled by sediments. Other drumlins are viewed as erosional ridges left upstanding between troughs scoured-out by violent subglacial meltwater outbursts (e.g., Shaw and Sharpe 1987). The total discharge during such flood events has been estimated to be on the order of 10^6 m^3s^{-1} and has been implicated in rapid global sea level rises which occurred at the end of the last glaciation (Shaw 1990).

The *deformational hypothesis* links drumlin formation to large-scale deformation of unconsolidated bed materials as a result of shearing stresses at the base of a moving ice sheet (e.g., Menzies 1987). Drumlins are thought to develop incrementally as resistant areas of sediment (drumlin cores) are drawn-out and streamlined beneath the ice. The development of high pore-water pressures in overridden sediments is considered to be an essential factor in reducing the strength of these materials to the point where they deform plastically and are streamlined into drumlins (Boulton 1987; Alley *et al.* 1987). Drumlins and flutes are considered to represent part of a continuum of subglacial bedforms produced by the interaction of ice and a deforming bed (e.g. Rose 1987). The deformational model predicts that the relative degree of elongation of these features is relative to the duration (i.e. length of ice occupancy) and intensity of deforming bed conditions (i.e. magnitude of shear stresses, ice velocity, etc.).

The well-developed drumlin fields of southern Ontario have recently become the focus of conflicting views concerning drumlin origin. Shaw and Gilbert (1990), observing drumlin orientation patterns in southern Ontario and upper New York State, concluded that these drumlins were formed during two separate catastrophic subglacial flood events (Algonquin and Ontarian). Drumlins and flutes in the study region are ascribed to an outburst which discharged southward from the Algonquin Highlands into upper New York State. The flow-lines they have constructed (Fig. 2.15) suggest that the meltwater train was measured on the scale of hundreds of kilometres in width.

More recently, Boyce and Eyles (1991) employed subsurface geologic data in the Peterborough drumlin field (Fig. 2.16) to show that these drumlins are largely erosional features resulting from deforming bed conditions during a last readvance of Late Wisconsinan ice (Simcoe lobe). They argue that the presence of an older (Early to Mid-Wisconsinan), regionally extensive stratigraphy within drumlin cores (Fig. 2.17, A,B,C,D) and the systematic down-ice variation in drumlin form (L/W; Fig. 2.17) precludes drumlin formation by catastrophic meltwater flooding (e.g., Shaw and Sharpe 1987; Shaw and Gilbert 1990). Extensively deformed drumlin till mantles which are thicker in the interdrumlin areas (Fig. 2.17) are considered to record channelized streams of deforming till progressively carved the drumlins from older, pre-existing sediments.

The drumlin exposed by the river meader within the park (530800/645450) referred to earlier provides important evidence in support of an erosional origin by subglacial deformation. The glaciolacustrine sediments (Sunnybrook and Thorncliffe Formation; Chapter 2.3.2) which form the core of this drumlin are regionally extensive deposits which pre-date drumlin formation and could not have formed as fluviatile infills of subglacial cavities. These drumlins are better explained by erosion of pre-existing sediments by deforming till streams (e.g., Boulton 1987; Alley *et al.* 1987; Boyce and Eyles 1991). Evidence for till deformation is indicated by the granulometry (e.g., Hibbert 1990), and by the presence of included sediments and deformed character (Boyce and Eyles 1991; Chapter 2.3.2) of the Halton Till which erosively mantles the drumlin core.

In addition, the meltwater hypothesis cannot account for the variability in the form of drumlins and flutes, or the existence of features which show multiple streamlining events (e.g., oval drumlins modified by flutes). The orientations of drumlins and flutes in the vicinity of the park point to an even more fundamental flaw in the flood theory; these features are unequivocally streamlined towards the northwest and could not have been formed by southward draining meltwaters during the Algonquin event proposed by Shaw and Gilbert (1990).

Ice Marginal and Proglacial Features

As the Late Wisconsinan ice sheet retreated, the Halton Till plain was successively uncovered and underwent limited modification in ice-marginal and proglacial environments. The recession of the ice margin to the southeast is marked by a series of poorly-defined moraine ridges developed on the northern part of the park tableland near Steeles Avenue (Map 1). These moraine ridges comprise linear swells in the till plain surface between 50 to 200 m in width which run transverse to the direction of ice flow.

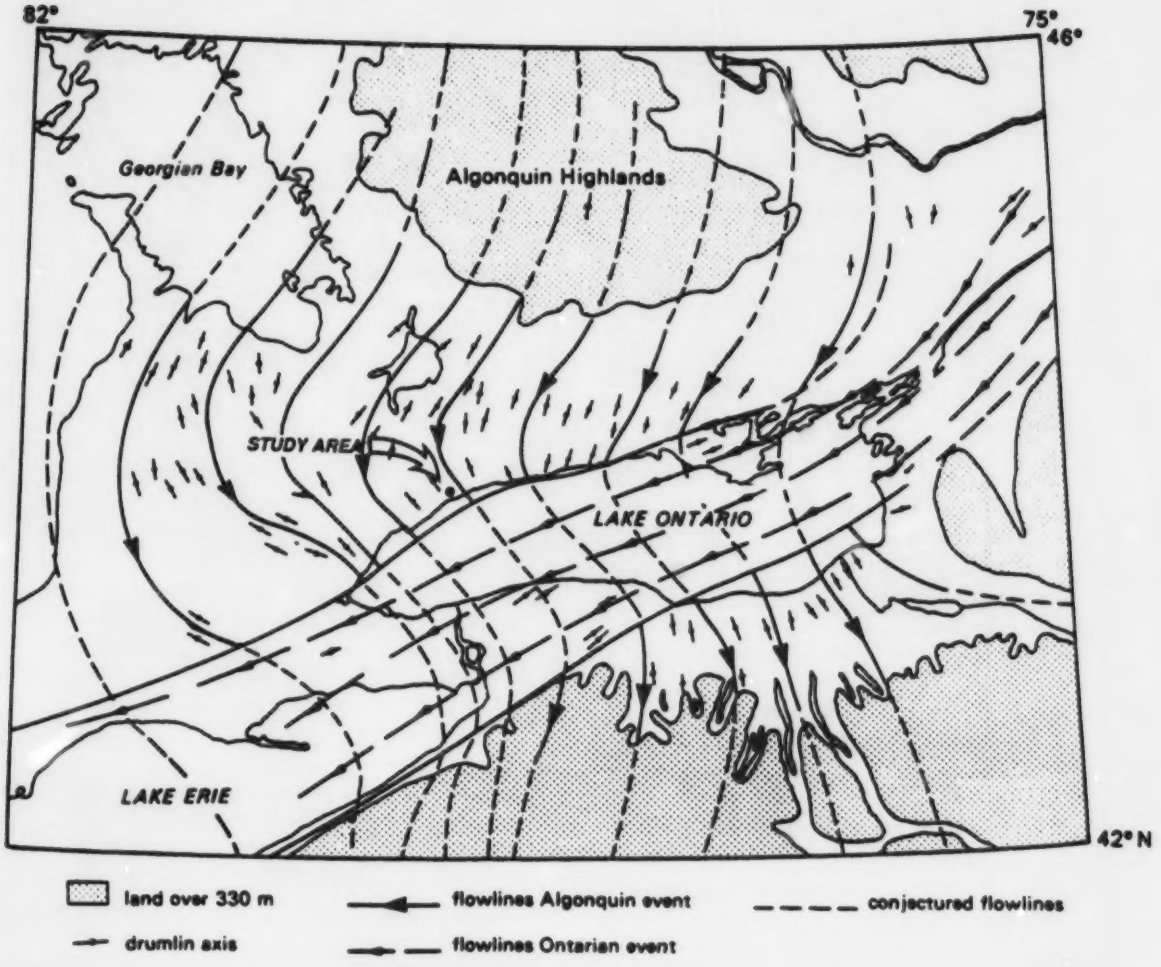


Figure 2.15 Proposed flow pathways of Algonquin and Ontarian flood events in southern Ontario and northern New York State (from Shaw and Gilbert, 1990).

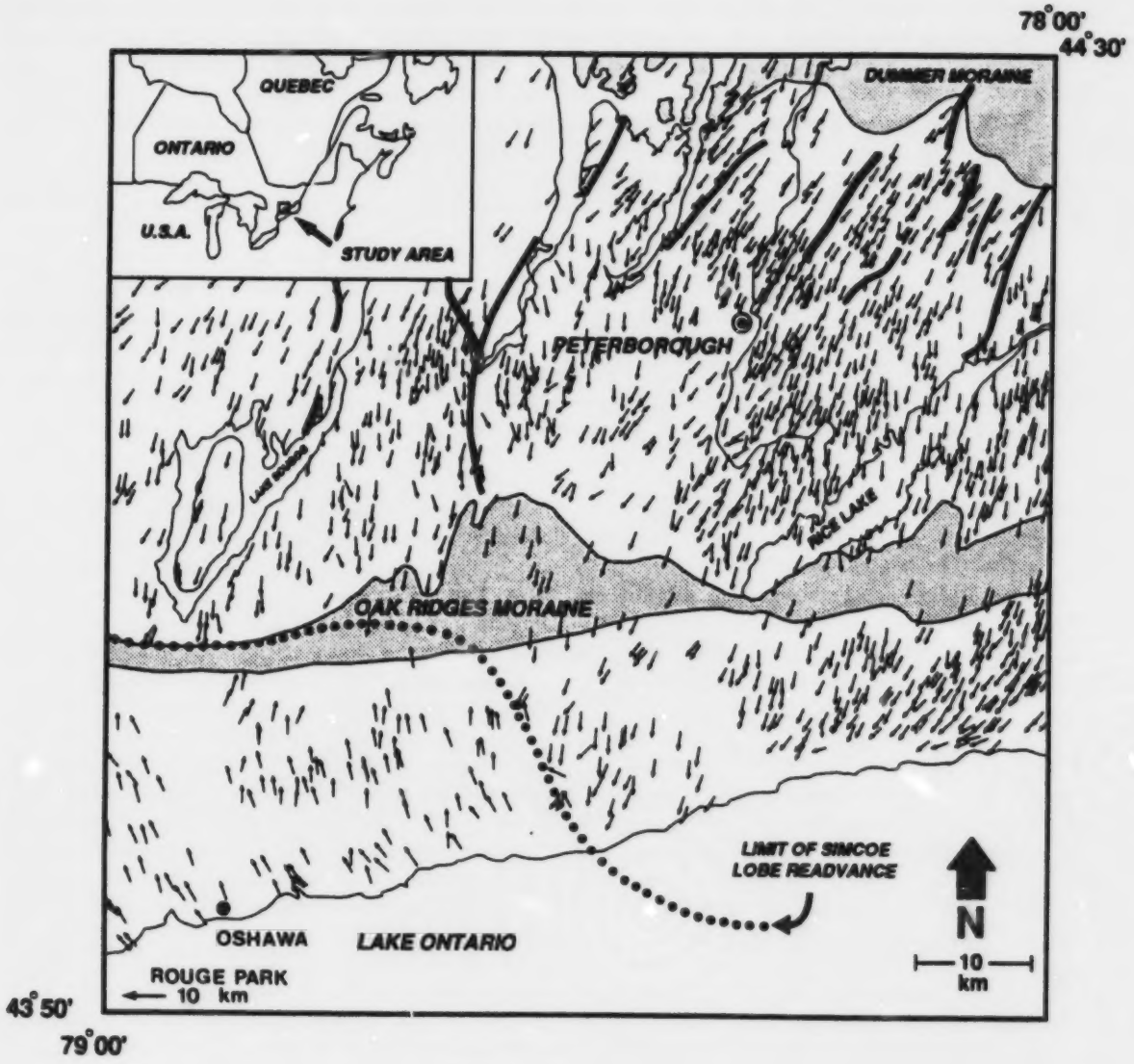


Figure 2.16 Distribution and orientation of drumlin (arrows) and eskers (bold lines) in the Peterborough drumlin field. Drumlin formation occurred during a readvance of the Simcoe lobe which overrode eastern half of the Oak Ridges moraine (from Boyce and Eyles 1991).

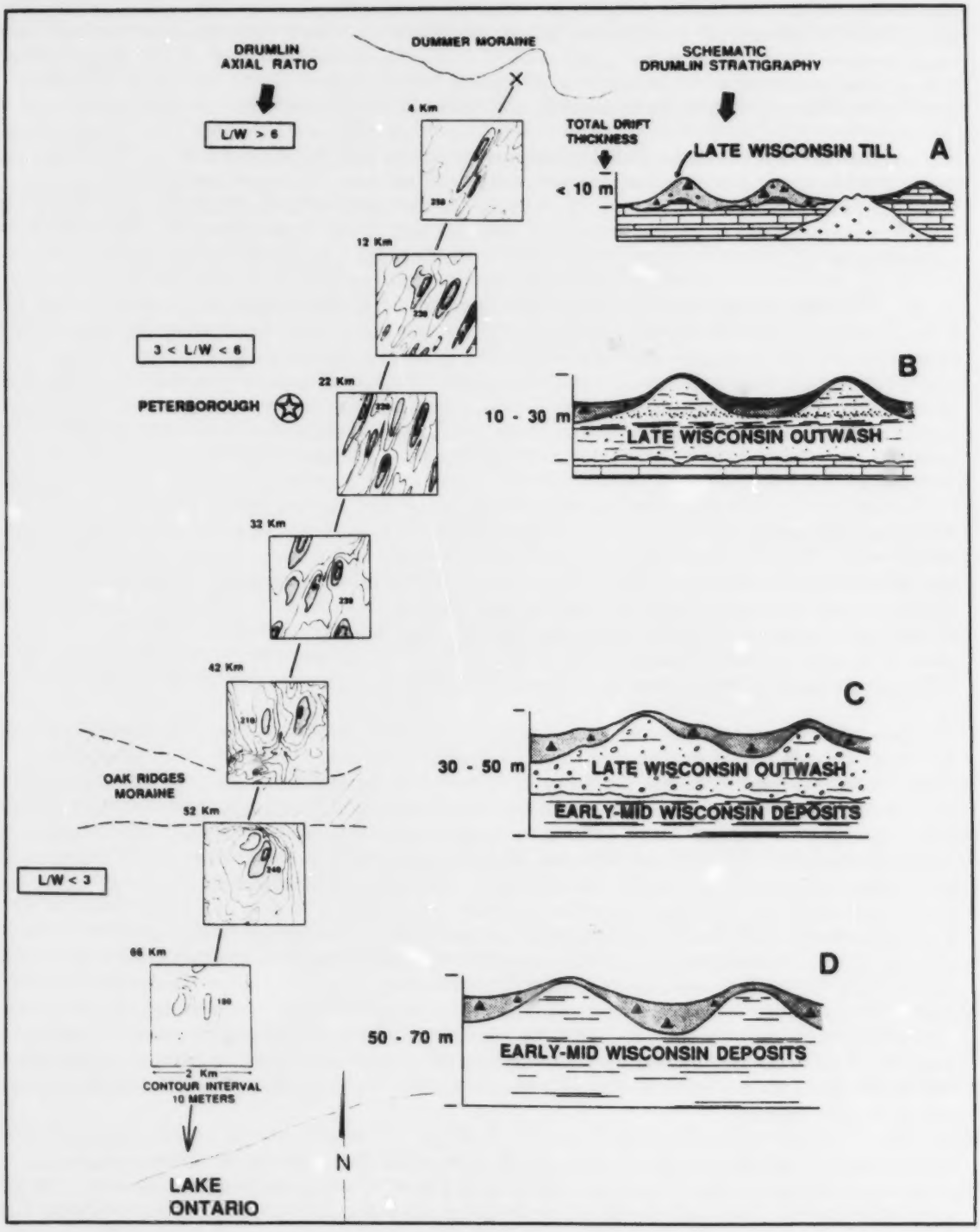


Figure 2.17 Variability in drumlin stratigraphy (cross-sections; A, B, C, D) and external morphometry, expressed as length to width ratios (L/W) along a 70 km ice flow line through the Peterborough drumlin field. Drumlin contour interval is 10 m (from Boyce and Eyles 1991).

The features are very low relief (< 5 m) and are not readily recognizable at ground level. On air photos these are delimited by dark areas of poorly drained ground which occur in the lows separating the moraines and can be traced for up to 800 m. These moraines have not been previously documented but are inferred to record brief halts or minor readvances of the ice margin as it withdrew from the region. During these brief stillstands, the moraines were likely formed by the extrusion of subglacially-deforming Halton Till at the ice margin.

It is possible that the moraines record annual melt cycles, in which case the distance between each ridge would represent the distance traversed by the receding ice margin in one year. Taking the average spacing of the moraines, a retreat rate of about 100 m yr^{-1} is obtained. At this rate, the Ontario lobe would have taken about 400 years to retreat some 40 km into the Ontario basin after abandoning its maximum at the Oak Ridges moraine sometime after 13,000 B.P.

As the ice retreated downgradient into the lake basin it impounded a series of small lakes along its margin and built outwash plains onto the till plain (Karrow 1967). Outwash deposits are represented in the vicinity of the park by thin (< 2 m) sand plains near Cherrywood (Map 1). Similar deposits probably extended along the glacial precursors to the Rouge River and Little Rouge Creek but have long since been removed by downcutting of the modern rivers. Ice marginal lakes were shallow, ephemeral features which occupied depressions in the surface of the till plain. These are represented in the park area by thin (< 1 m) silts and clays perched on the tablelands along the Rouge and Little Rouge river valleys north of Finch Avenue (Map 1).

Lake Iroquois Features

The end of the last glaciation was marked by the high-level Lake Iroquois in response to damming of the St. Lawrence outlet by ice remaining in the Kingston area. This lake is recorded by a regionally extensive shoreline and associated lacustrine sediments (littoral sands, gravels, deep water silts and clays). Within the park area, many of the nearshore features of Lake Iroquois have been lost to aggregate mining and urban development but have been delineated on surface maps on the basis of historical air photo coverages dating from the early 1930s.

The shoreline of glacial Lake Iroquois passes through the park area, oriented southwest-northeast (Map 1). Regionally around Lake Ontario, this consists of a marked bluff up to 30 m high (Fig. 1.12; Chapman and Putnam 1984), but in the study area, the former shoreline is only poorly defined and comprised, prior to extensive mining, a complex of shingle beaches and sandy embayments backed by a shore terrace cut in the Halton Till (Map 1). The only visible remnants of the Iroquois terrace presently surviving within the park is a low (5 m), flat-topped embankment located near the northwest corner of the Beare Road landfill just west of the CNR tracks (540000/648050) and within the confines of Metro Zoo (485300/646000). At the first named locality, the terrace has been degraded by slope processes and by the downcutting of a small tributary of the Little Rouge Creek which follows the terrace base. A well developed terrace can be observed 3 km to the northeast of the study area, where the Iroquois shoreline rises up to 20 m above the CNR tracks north of Finch Avenue (Map 1). Analysis of air photos (*circa* 1931) reveals the presence of at least two terraces below the level of the main Iroquois bluff (approximately 5 m and 11 m respectively), in the area now occupied by the Meadowvale Road underpass (Map 1; 530280/646520, 530100/646800). These terraces probably record the establishment of lower lake levels as a result of the progressive uncovering of the St. Lawrence outlet, and stepwise lowering of Lake Iroquois (e.g., Anderson and Lewis 1985; Fig. 1.12) as the Late Wisconsinan ice withdrew to the northeast.

In the vicinity of the study area, the Iroquois shoreline was frequently interrupted by shallow embayments occupying northwest trending lows between drumlins and flutes. The largest of these embankments extended 1.8 km northwest of the Beare Road landfill and is now occupied by an eastern tributary of the Little Rouge Creek. The embayments are floored by sands and gravels eroded from their headlands in the Halton Till.

Lake Iroquois accumulated extensive beach and nearshore deposits at a number localities along the length of its shoreline (Fig. 1.8). Morphologically, the Iroquois beaches consisted of a series of shore-parallel ridges and

beach barriers which coalesced to form extensive strand plains. In the park area, the strand plain formerly extended more than 1 km south of the Iroquois terrace, blanketing the area now occupied by the Beare Road landfill and the Metropolitan Toronto Zoo (Map 1).

Well developed beach barriers, up to 50 m in width and over 300 m in length are visible on historical airphotos at a number of points along the former shoreline (e.g., 530450/646480). Prior to extraction for aggregate, the beach deposits were locally up to 5 m in thickness, and consisted primarily of variably-bedded sands interstratified with shingled gravels and boulder lags. These sediments were derived by erosion and reworking of the Halton till plain, through a combination of wave attack along the coast, and denudation of the landsurface.

The fossil beaches of Lake Iroquois generally coincide with the drainage routes of present-day rivers flowing into Lake Ontario (Fig.1.8). Most of these rivers were established as meltstreams in the late stages of the last glaciation, and apparently, they constituted important sediment inputs which controlled the construction of beaches along the Lake Iroquois coast.

Southward of the Iroquois beach, sedimentation in deeper, sub-littoral waters (10 to 60 m depth) is recorded by extensive areas of thin (< 2 m) sand and clay which drape and infill the till plain surface (Map 1). Lacustrine sands occur dominantly between 130 and 100 m a.s.l and cover some 18 km^2 in eastern Scarborough and western Pickering Township, including the southern portion of the park tablelands. Associated deep water clays are more restricted in extent and occur generally in the vicinity of the present Lake Ontario shoreline below elevations of 100 m a.s.l. The surface of the Iroquois lake plain is relatively flat and featureless above 120 m elevation, reflecting significant erosion and levelling of the Halton Till plain by wave activity. To the south, below the Lake Iroquois wave base, the characteristic drumlinized and fluted topography of the Halton Till plain emerges and is draped locally by a thin veneer of lacustrine sediments.

2.4.2 Postglacial Assemblage

Fluvial Features

The association of ice-marginal lake deposits with modern river valleys is marked across the region (Fig. 1.8) and suggests that most modern streams, including the Rouge River and Little Rouge Creek, were established as meltstreams during deglaciation. The downcutting of these streams began in the early postglacial era as a result of lowered lake levels following the drainage of glacial Lake Iroquois after 12,100 B.P., and is recorded by well-developed, high-level terraces along the Rouge and Little Rouge (Map 1).

Abandoned river terraces are most prominent on the Rouge River in the vicinity of Finch Avenue and Sewells Road, where five are recognized (Map 1; 540340/644490). The highest terrace stands about 20 m above the modern river level and marks the former position of a small meander loop. About 400 m south of Finch Avenue, two well-developed terraces are incised on a small upland which separates the present river course from a large abandoned meander (530400/645400). The river stood about 10 m above its present level when it occupied the abandoned segment. Extensive mining of gravels along the banks of the two rivers (Map 4) has also produced numerous flat-topped ridges which are sometimes difficult to differentiate from the fluvial features.

The present base level of erosion is about 2 km upstream of the confluence of the Rouge River and Little Rouge Creek. Upstream of this point, the streams are actively downcutting their beds and eroding streambanks. The segments of the two rivers between Twyn Rivers Drive and Finch Avenue, are characterized by well developed pool and riffle sequences consisting of coarse gravel bars alternating with shallow basins floored by finer sediments. Coarse gravel and cobble point bars are well developed along these stretches, particularly on the Little Rouge just north of Twyn Rivers Drive (e.g. 520700/480000). The streambeds contain outsize boulders up to 0.75 m in diameter which are inferred to be remnants of aggregate mining activities along the river; the boulders exceed the size of 'normal' bedload but may have been transported some distance during periods of extreme flood discharge (e.g., Hurricane Hazel in 1954). The coarseness of sediments forming the streambeds

along these stretches undoubtedly reflects, to some extent, the reworking of Lake Iroquois beach deposits. To the north of the abandoned Iroquois terrace, streambed materials are noticeably finer and consist mainly of sand and silt with minor gravel and cobble bars. The fining reflects a shift in the dominant sediment source, from gravelly Lake Iroquois sediments to the sand-rich Halton Till which is the predominant substrate north of the abandoned Iroquois shoreline.

The lower 5 km of the Rouge River and Little Rouge Creek represent 'drowned' river valleys which are slowly being infilled (aggraded) as a result of rising lake levels. Lake Ontario is rising at an estimated rate of 0.23 m per 100 years (Clarke and Persoage 1970; Kite 1972) in response to continued isostatic rebound of the eastern end of Lake Ontario (Fig. 1.12; Chapter 1.3). The aggradation of alluvial materials has built a broad floodplain up to 500 m in width across the valley floor (Map 1). Streambeds are constructed dominantly of sand and silt (Fig. 2.14) with minor amounts of gravel, reflecting low stream gradients, reduced competency of flows and attrition of coarse sediments along the lower reaches.

The mouth of Rouge River (Map 1) is protected by a 10 m high, sand and gravel spit built by a combination of fluvial transport and longshore drift of sediment (e.g. McGillivray 1974). Sediment drift along the north shore of Lake Ontario is dominantly from east to west (Fig. 1.12) but is locally reversed at a number nodal points along the coast. The eastward transport of sediments at the mouth of the Rouge is the result of drift divergence at a node located at East Point, 6 km to the southwest (Davidson-Arnott *et al.* 1982). The process is evident on some aerial photos which show an eastward extending plume of sediment debouching from the river mouth.

Air photograph coverage shows that the spit and the river outlet have maintained the present configuration at least since the early 1930s, but are slowly being inundated by rising lake levels. This is most evident in the growth of ponds and extensive swamps and marshes inland of the spit. The lower 5 km of the Rouge River system has not been studied in detail by geologists but the history of development of this area is likely similar to that identified for Grenadier Pond and Frenchman's Bay (McCarthy 1986; McCarthy and McAndrews 1988), and Sixteen Mile Creek (Flint *et al.* 1988). Palynological and sedmentological evidence from these sites indicates unusually rapid rises in lake level at 2,000 and 3,000 B.P. resulting from regional changes in precipitation and temperature.

Valley Side Slopes

Subaerial processes such as mass wasting and slope wash have acted concomitantly with fluvial downcutting to produce the steep side slopes which characterize the Rouge River Valley. These geologic processes are still active in the study area today and are indicated by areas of active slope erosion shown in Map 4.

The gradient of the valley sides as measured from topographic maps typically range between 20° to 30° on vegetated slopes, and from 40° to near vertical where slope erosion is actively taking place. Most slopes in excess of 30° show signs of slope movement in the form of inclined trees and soil creep. Actively eroding bluffs within the park can be classified into two major slope types: planar slopes which show either a flat or stepped profile, and scalloped slopes, consisting of erosional bowls and deeply incised rill channels.

Planar slopes are characterised by a straight cliff-crest line and steep, near-vertical, faces which terminate below in a lower angle talus slope. These are relatively stable slope forms which result from parallel slope retreat by sloughing of surface sediment and slab failure of competent strata (e.g. Sunnybrook and Halton Till) along stress relief joints parallel to the cliff face (Bryan and Price 1980; Eyles *et al.* 1985b). The processes are most active during spring snow melt and are triggered by high porewater pressures generated by groundwaters trapped beneath an impervious layer of frozen sediment on the slope face. The groundwaters are released rapidly as the face thaws, causing extensive soil piping, caving, block failure and minor debris flow activity. Well developed planar slopes can be observed within the entrenched meander in the vicinity of Twyn Rivers Drive (Map 3; R 7, R 8). At this location, extensive spring sapping occurs along the base of the Thorncliffe sands where they overlie the relatively impermeable, clay-rich Sunnybrook Till (Fig. 2.13).

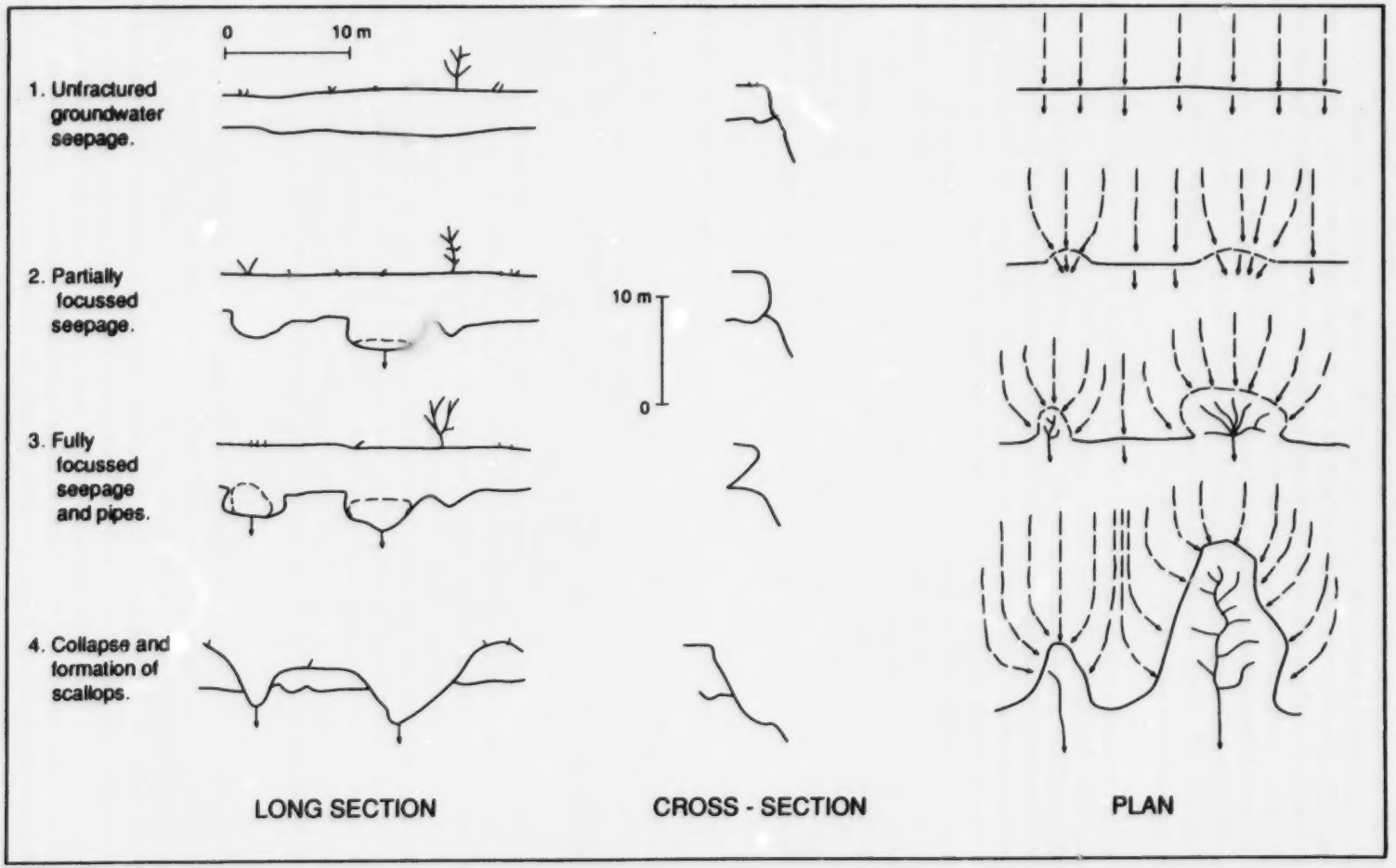


Figure 2.18 Formation of erosional scallops by spring sapping in response to groundwater focusing within 'sag basins' on top of impermeable Sunnybrook Till (from Eyles et al. 1985b).

Scalloped slopes are more unstable slope forms produced by the incision and headward retreat of gullies into the cliff face. The scallops begin as minor rills eroded in the cliff face where seeping groundwaters are focused in 'sag basins' (Fig. 2.18). These develop where sand aquifers rest on relatively impermeable tills. Erosion takes place chiefly as a result of mudflow activity in the spring when seeps are most active, and to a lesser extent by fluvial dissection during heavy rain events in summer months (Eyles *et al.* 1985b). Rills are progressively dissected into gullies and eventually amphitheatre-like bowls develop, which are separated by free-standing spires and aretes. Scalloped slopes are best developed within the park along the western boundary of the Metropolitan Toronto Zoo (Map 3, R 15). The 35 m high cliff here is a relatively 'youthful' scalloped slope showing well-developed rills, gullies and resistant pinnacles or 'hoodos.'

Slope erosion is locally a problem in the park area since large volumes of sediment are released to the river degrading aquatic habitats (Chapter 3.2). Sideslopes adjacent to the Hydro corridor (Map 4) are particulary problematic and some effort at revegetation is required. Significant degradation and erosion of footpaths and trails by horses is a recurring problem throughout the Park area; an emerging problem is the use of mountain bikes and off-road motorcycles.

CHAPTER 3: PLANNING CONSIDERATIONS

3.1 Significant Features

The earth science features found in the Rouge park area vary in their significance from local (L), regional (R) to provincial (P), and are listed in Table 1 under three principal theme headings. These are Paleozoic bedrock features, Quaternary features (glacial and postglacial) and man-made features.

Paleozoic Bedrock Features

The Paleozoic bedrock outcrops at P1 and P2 (Map 4; Table 1) are of provincial importance and of high interpretive value for the public. Both outcrops contain a diverse marine faunal assemblage which includes representative fossils of the trilobite *Triarthus rougensis* and the graptolite *Climacograptus rougensis* (Appendix A). The outcrop at P1 is also the **type section** for the middle member of the Whitby Formation. Interpretive themes could encompass discussion of the geologic development of Paleozoic North America, plate tectonics and continental drift, fossil communities and evolution. Well developed joints and faults present in the Rouge bedrock outcrops and overlying Quaternary sediments have recently been attributed to regional neotectonic activity (earthquakes) during the last 80,000 years. The two outcrops are the only accessible bedrock exposures in the eastern Toronto area and are the focus of ongoing studies by government and university groups to assess the future potential for seismic hazard in the region. Themes could be developed for the public relating to the nature and causes of movements of the Earth's crust and its impact on man and his environment.

Quaternary Glacial Features

The outstanding earth science feature in the Rouge Park is the exposure of Don Beds, Scarborough Formation and associated faulted bedrock at Section R022 (Fig. 2.7; Table 3, Map 3). Given the scientific importance of this locality, the site is of **international** significance. Together with the closely adjacent Section R020, which exposes the Scarborough Formation, Halton Till and Iroquois Sands, it is of additional importance in terms of seismic hazard assessment in southern Ontario and New York State. These sections are of very high interpretive value and could be the focus of themes relating to climate change, glaciation, ice sheets, isotope investigations and seismic hazards. The area along the Rouge River Drive adjacent to Twyn Rivers is clearly the centre-piece of a major interpretation theme centred on the Quaternary history of the park and the surrounding Toronto region. Whilst outcrops of these strata occur elsewhere in the region (Scarborough Bluffs, Don Valley Brickyard) they are increasingly being lost to remedial engineering schemes and urbanization and are not interpreted for the public. The large-scale faults and related structures present in the Don Beds and Scarborough Formation are currently being investigated as part of a regional earthquake hazard assessment. It is critical that the integrity of the sites be maintained for the future, to allow evaluation of these structures in light of changing ideas and new approaches to seismic hazard investigation and for paleoenvironmental interpretations of these fossiliferous strata.

A number of other outcrops in the study area expose representative examples of late Quaternary strata (York Till, Scarborough Formation, Sunnybrook Till, Thorncliffe Formation, Halton Till; R3, R6; Table 1, Map 4) which are of regional importance; although better exposures occur elsewhere (Scarborough Bluffs), these outcrops provide important information regarding the regional extent, thickness and stratigraphic variability of the these units. The outcrops along the entrenched Rouge River meander (R6; Table 1) provide the best exposure of the Thorncliffe Formation in the park and show well developed bedding structures which are of high interpretive value. Themes could be developed here relating to interstadial/stadial climates, lacustrine sedimentation processes and the formation of deltas. The outcrop at site R6 (Table 1, Map 4) is one of the few known exposures of the York Till in the region but is poorly exposed and of low interpretive value for the public.

Specific localities in the study area also provide regionally important examples of the glacial evolution of the region. Drumlins and flutes (R1, R2a, R2b, R5; Table 1; Map 4) on the northern park tableland for example, are of high interpretive value in that such landforms are well developed and highly visible at these localities. The elongate drumlin dissected by the entrenched Rouge meander at locality R1 (Table 1; Map 4) is also of high scientific value; the drumlin's well exposed internal stratigraphy provides evidence critical to the evaluation of conflicting ideas regarding drumlin origin. An interpretive station placed at this site could present the current theories of drumlin formation and weigh them in light of this evidence. Low relief, transverse moraine ridges developed on the northern park tableland (R4; Table 1) are not easily viewed in the field and are of moderate interpretive value. The origin of these features is uncertain but they may yield important information regarding the movements and extent of Late Wisconsinan ice in the region and should be preserved for further scientific study.

The drumlins, flutes and moraine ridges form part of a northern tableland region of the study area (L1; Table 1, Map 4) which offers a representative subglacial terrain typical of the Halton Till. The terrain type is rapidly being lost to urbanization in other parts of the region.

The Iroquois shoreline remnants and sand plains (L2, L3; Table 3; Map 4) are of low interpretive value since they are not well developed within the park area and are not easily viewed in the field. Because of their better development elsewhere these features are considered to be of local significance.

Quaternary Postglacial Features

The postglacial features of the park are generally of local interest and significance, but regionally significant features include the well developed, high-level terraces in the vicinity of Finch Avenue (both of these are also of high visual profile and high interpretive value) and the marshlands and spit system at the lakeward termination of the Rouge River. Illustrative themes could centre on changing lake levels, the associated river response and biological community development. The postglacial downcutting of the Rouge and Little Rouge rivers and the flooding of the mouth of the Rouge River is probably typical of many of the rivers draining into Lake Ontario (e.g., Humber, Don, Highland, Duffins) and thus has a wider regional interpretive significance.

Man-Made Features

The Beare Road landfill is the largest feature in the region south of the Oak Ridges moraine and could be made more attractive through imaginative reforestation. The landfill stands up to 120 m above the surrounding tableland and affords an excellent viewpoint across the park toward downtown Toronto. An interpretive centre for the park could be located on the landfill; this could be the focus for interpretive earth science themes illustrating the regional geological evolution. Themes could also developed which relate to mans' use of the regions' geologic resources (e.g. aggregate mining along the Iroquois shoreline; use of abandoned gravels pits as landfills) and the related impacts on the natural environment. The landfill is centrally located in the park and is already well served by roads. The possibility of using methane for power should be explored, thereby illustrating another earth science theme.

TABLE 1: SIGNIFICANT EARTH SCIENCE FEATURES

Area[*1]	Feature(s)	Description and Significance	Interpretive Value[*2]
Palaeozoic Geologic Features			
P1	Whitby Formation outcrop (R 23)[*3] Rouge River	Representative section of middle Whitby member, type locality for *Triarthus rougensis* and *Climacograptus rougensis*.	A
P2	Whitby Formation outcrop (LR15), Little Rouge River	Excellent exposure, showing well developed orthogonal joints related to neotectonic activity; of provincial significance as earthquake hazard evaluation site. Together these two sites are the only accessible bedrock exposures in the eastern Toronto area.	A
Quaternary Geologic Features			
GLACIAL FEATURES			
P3	Quaternary section (R020) exposing Scarborough clays, Halton Till and Iroquois sands, on Rouge River, vicinity of Twyn Rivers Drive	Large-scale normal faults in Scarborough Formation possibly related to bedrock joint structures; of Provincial importance in earthquake hazard assessment. Locally important as most clearly exposed section through Scarborough clays in park area.	A
P4	Quaternary and bedrock section (R022) exposing faulted Whitby Formation shales, Interglacial Don Beds and Scarborough Formation on Rouge River south of Twyn Rivers Drive.	Of **international** scientific importance as it provides the only other outcrop known in the Toronto region of richly-fossiliferous last-interglacial sediments. Other outcrop is poorly exposed in Don Valley Brickyard. This site is also of importance for earthquake hazard assessments of associated fault structures.	
R1	Elongate drumlin dissected by Rouge River, vicinity of Finch Avenue.	River sections expose drumlin internal stratigraphy; of regional significance in determination of origin of these features.	B
R2a	Flutes, vicinity of Steeles Avenue and Pickering Townline.	Exceptional development of low, narrow flutes which record ice moving to the northwest.	A
R2b	Fluted terrain, vicinity of Sewell's Rd. and Steeles Ave.	Well developed fluting, consisting of individual ridges and groups of flutes up to several km in length.	B
R3	Quaternary section LR 19) exposing York Till, north of Kingston Road.	One of few known outcrop localities in region where York Till is present.	C
R4	Ice-marginal moraine ridges on northern park tableland.	Transverse moraine ridges are known from only a few localities in the region and their origin is not well understood at present. The features could be of considerable use in regional reconstructions of Late Wisconsinan ice extent and movements.	B
R5	Oval drumlin, Reesor Road.	Best example of low, oval drumlin type in the park area.	A
R6	Exposures of Sunnybrook Till, Thorncliffe Formation, Halton Till (R006, R007, R008) within entrenched meander north of Finch Ave. on Rouge River.	Best exposure of Thorncliffe Formation in park area; well developed vertical, planar slopes.	A
L1	Northern park tablelands of the study area.	Well developed glacially streamlined topography showing a variety of drumlin and flute morphologies.	B

TABLE 1: CONTINUED

Area*1	Feature(s)	Description and Significance	Interpretive Value*2
GLACIAL FEATURES CONT'D			
L2	Iroquois shoreline remnant, vicinity of Beare Road.	Although poorly preserved, this comprises the only remnant of the abandoned Lake Iroquois terrace in the park area.	C
L3	Lake Iroquois sands, southern park tablelands.	Only remaining area in park where the littoral deposits of Lake Iroquois are preserved.	C
POSTGLACIAL FEATURES			
R7	Rouge river mouth, spit and associated marshes.	Drowned river mouth with protective spit produced by interaction of fluvial and longshore drift processes and subsequently modified during railway construction. Encroachment of Rouge floodplain by marshes in response to rising lake levels. Major recreational area in winter and summer. Rich aquatic habitat.	B
R8	High-level river terraces, vicinity of Finch Avenue.	Well developed terraces recording various stages in the downcutting of the Rouge River.	A
R9	Alluvial floodplains on Rouge and Little Rouge south of Twyn Rivers.	Broad floodplains recording aggradation of sand and silt in lower reaches of rivers in response to rising lake levels. One of few rivers in region where development of floodplains is recorded in historical air photo coverages.	B
R10	Modern cutbanks widely exposed along Rouge and Little Rouge rivers (e.g. R025, LR017).	Cutbanks show well-defined stratigraphy of flood-generated, overbank sands and interbedded soils and peat. An excellent record of flooding is preserved; of importance to studies of drainage basin hydrology.	
L4	Meandering stream channel, Rouge River and Little Rouge Creek north of Twyn Rivers Drive.	Good development of pool and riffle sequences, gravelly point bars, river bank erosion.	B
L5	Hoodos, Rouge River vicinity of Metro Zoo	Well developed scalloped slopes, showing deeply incised gulleys and hoodos.	B
L6	Planar slopes, Rouge River near Finch Ave. and Sewells Rd.	Near vertical slopes produced by parallel retreat and slab failure.	B
Man-Made Features			
SI	Beare Road landfill.	Largest topographic feature south of the Oak Ridges moraine. Excellent viewpoint over park with good access. Possible location of interpretive centre.	A

*1 Level of significance of feature(s) contained within area:
- P = Provincial
- R = Regional
- L = Local
- SI = Special Interest

*2 Interpretive value of earth science features:
- A = High
- B = Moderate
- L = Low

*3 Code in bracket references outcrop locality number from Map 3.

3.2 Protective and Remedial Measures

Several areas within the study area can be identified where protective or remedial measures are required to preserve significant earth science features. Especially in the case of mitigative activities, detailed discussion of these measures would require specific field investigations (e.g., slope stability studies) on a case by case basis. However, features in need of protection are identified here and possible steps to be taken are outlined.

As identified by Cordiner (1983), the provincially important Paleozoic bedrock outcrops within the park (Map 3; R 23, LR 15) are susceptible to river bank erosion and slumping. The present rate of 'natural' fluvial erosion of these outcrops is small (probably less than a few mm per year) and is not deemed to pose a significant threat to their preservation. However, loss of outcrop through slumping of overlying Quaternary sediments is potentially a more serious problem. The mass movement of unconsolidated materials is a naturally occurring process on slopes within the park area but is greatly exacerbated by devegetation of slopes and increased surface run-off associated with nearby urban development.

The slope immediately above the Whitby type section on the Rouge River (R23) is largely bare of vegetation and shows visible signs of slope movement (Fig. 2.6). A 30 m long section of the downstream end of the outcrop is obscured by slump which occurred during the spring melt of this year (1991). A programme of revegetation might be attempted above the slope to improve its stability and prevent further outcrop losses.

The bedrock outcrop on Little Rouge Creek is less affected by top slope instability (Fig. 2.5) but is susceptible to increased stream erosion by surface run-off collected from Twyn Rivers Drive and possible housing projects upstream on a small creek which enters the Little Rouge mid-way along the bedrock exposure. Erosion and sediment run-off along the creek require site specific study to maintain present flow regimes and avoid future remedial measures.

Both outcrops are remote from existing, well-developed trail networks and should remain so in future to prevent their degradation by public activities. The collection of fossils from the bedrock outcrops should be prohibited except for permitted scientific study.

The internationally and provincially significant Whitby, Don and Scarborough Formation outcrops on the Rouge River and Little Rouge (Sections R020, R022, LR015; Map 4; Table 1) are undergoing parallel retreat (*ca.* < 25 cm yr^{-1}) as a result of fluvial and slope processes. The impact of future developments, particularly any upgrading of the adjacent bridge and road approaches which are heavily used by rush hour commuters, must be considered in the park planning process to ensure the preservation of these features. All of the existing stratigraphic exposures along the rivers are natural sites of stream erosion and proposals to "stabilize" them should consider their significance, interpretability and "naturalness."

At other locations, more significant erosion of river bluffs (> 0.5 m yr^{-1}; e.g. Eyles *et al.* 1985b) occurs along the Rouge River and Little Rouge Creek north of Twyn Rivers Drive (Map 4). Erosion of is most prevalent on south-facing slopes in the vicinity of devegetated Hydro power corridors (e.g. R 16, LR 12, LR 13; Map 3). These slopes are unstable and are a potential hazard to the public where they are retreating adjacent to existing riverbank trail systems (e.g. on Little Rouge River just south of Hydro corridor; LR 13; Map 3).

Significant slope erosion can threaten the viability of aquatic habitats by introducing suspended sediments to the river systems. Most rapidly retreating slopes are badly slumped and are of little scientific or interpretive value; these should be stabilized where possible through a programme of revegetation and surface run-off management. However, it cannot be over- emphasized that the erosional retreat of bluffs is a **naturally occurring process** and that judicious management measures should be applied **only** where unstable slopes present a threat to public safety or to the viability of the river ecosystem.

Areas of substantive surface soil erosion away from the rivers (Map 4) also contribute to sediment loading of the rivers. These are associated with land stripping for construction of new housing developments along the crest of

the river valleys, and with devegetated zones comprising the Ontario Hydro right-of-way and the Beare Road landfill. The devegetated areas are particularly problematic since they are located on easily eroded, cohesionless, sandy soils (Iroquois sands) which cap much of the southern park tablelands (Map 2). A programme of revegetation is required in these areas to inhibit soil loss and to reduce the impacts of stream turbidity and siltation stress on aquatic habitats. Tableland sedimentation ponds serving the management needs of individual developments should be a requirement of any new (and many of the existing) developments so that runoff entering the park area should be of suitable quantity and quality. The use of horses and mountain bikes should be regulated so as to prevent erosion of footpaths and trails.

3.3 Recommendations

The study area will be under increasingly severe pressure as a result of urbanization upstream, outside of the park boundaries and along the margins of the Rouge River system downstream. **This is the greatest threat to the future maintenance of the park environment.** Urbanization of catchment areas results in greatly enhanced suspended and dissolved sediment inputs from deforested slopes and tablelands and enhanced pollutant loadings in spring and storm run-off from roads and gardens. Highland Creek and the Don River are local examples of the derogatory effects of urbanization adjacent to river valleys (Neuhold 1975) and where recreational use of these rivers by the public has been banned because of pollution. Routing of the proposed highway 407 across the Rouge River to the north of the park (Fenco 1990) and expansion of the 401 bridge crossing will have major impacts on the downstream basin; salt loadings during winter and spring will be a major problem. Discussions with Ministry of Transport engineers regarding these impacts are recommended.

Of special concern is that the present study area's boundaries essentially follow the crest of the valley sideslopes; the park only extends onto the surrounding tablelands north of Twyn Rivers Drive and the Metro Zoo. To the south, urban areas have encroached and continue to encroach directly adjacent to and on to valley sideslopes. Construction of new developments to the east of the Little Rouge near Twyn Rivers Drive at the old Glen Eagles Hotel site, and elsewhere will impact river discharge characteristics, quality and aquatic habitats downstream. Bigger setbacks along the park sideslopes should be established. Stringent stormwater and surface water management practices must be employed with the objective of allowing no deterioration of water quality and no increase in the peak flood runoff and associated erosion that results from urbanization.

1) Protection of the Rouge River catchment, beyond the existing area designated for the Rouge park must be secured. If this is not done, the park's valleyland geomorphology will be negatively impacted by upstream developments as the Metropolitan Toronto region expands. Stringent setback and landuse controls similar to those being implemented for the Oak Ridges moraine should be extended north of the present park boundaries, in the valleylands, to conserve and preserve as much of the drainage basin as possible. The hydrogeologic significance and environmental sensitivity of the Oak Ridges moraine indicates that protection of the entire catchment should be a major objective. The development of a comprehensive basin management strategy for the watershed (M.T.R.C.A. 1990), based on detailed urban drainage studies, is a positive step forward. Its recommendations for an integrated, cooperative approach to the watershed ecosystem should lead regulatory agencies towards more environmentally effective ways of balancing development with conservation.

2) There are insufficient baseline data available with regard to **present** water quality and run-off characteristics to be able to monitor or model **future** changes in the Rouge River and Little Rouge Creek. A comprehensive study of ground and surface waters in the Rouge Valley Park and upstream is required, as recommended by the Crombie Commission on the Toronto Waterfront and Watershed Area (1989) and the Greater Toronto Greenlands Strategy (Intera-Kenting 1990), both of which stressed the protection and management of the urbanized drainage catchments sourced in the Oak Ridges Moraine. The Rouge River park provides a unique and last opportunity to ensure the continued natural viability of a river system in the Greater Toronto Area; the chemistry, flow and biology of other rivers have been heavily impacted by urbanization.

3) Provincially significant geological features identified in this study should be treated as nature reserve zones in the proposed park, with strict control and regular monitoring of human activities.

4) Regionally significant features and terrain types should also be considered for nature reserve status in the park, or otherwise be assured of protection from degradation of their features. Such features are not deliberately protected in other conservation lands in the region. For example, the drumlins, the flutes, the ice marginal moraine ridges, the sections showing representative Quaternary strata, the rivermouth spits and drowned rivermouth valley, are not presently protected in any formally recognized conservation lands in the region. It is not realistic to expect that such features will be protected for their inherent scientific and educational values anywhere else in the Greater Toronto Area.

5) Features and landforms of local significance (e.g. stream channel and valley side slope features) are also important attributes of the study area and should be afforded protection from landscaping or other activities altering the topography. Park zoning other than nature reserve would be appropriate from a geologic point of view.

6) The park is more than well-served by existing trails and footpaths; no new trails should be built unless designed to channel traffic or rationalize the closure of other trails. A trail plan should be developed to ensure the environmental integrity of all the trails and to redirect inappropriate foot traffic, such as presently occurs along a number of stream and bluff edges. 'Upgrading' of existing trails, such as boardwalks, should be resisted unless they conserve existing environments.

7) Fossil collecting should be prohibited, except for permitted scientific research.

While not directly related to the park's geology, it is the authors' opinion that the continued and very heavy use of Twyn Rivers Drive by vehicles is inappropriate in the core of the park. The most significant geological outcrops in the park (Whitby Formation Shales, Don Beds and Scarborough Formation) are all in close proximity to the road, and increased access and use will degrade those features over time.

A primary goal of the park management should be public education and increased awareness of the long environmental history of the Toronto region as a whole. At present there is no earth science interpretation centre in southern Ontario. The fragility of present day natural environments and the need for conservation and ecological protection of our local, regional and global environment is a second theme.

The Beare Road landfill provides an exceptional interpretive vantage point. It is the authors' opinion that a park interpretation centre could be appropriately engineered and located on the former Beare Road landfill. The site is well-accessed by existing roads, and the use of the site for an interpretive centre would be an appropriate 'metaphor' for an urban park. The geology of the urban environment should be interpreted within the broad context of the Toronto region, linked with complementary themes expressed in such sites as the Don Valley Brickyards, Scarborough Bluffs, Iroquois shoreline, Toronto Islands and the Woodbridge railroad cut.

GLOSSARY

aggregate - sand and gravel mined for construction needs.

amphipod - any crustacean belonging to the order Amphipoda, lacking a carapace and having a laterally compressed body.

alluvium - sediments deposited by streams.

anion - negative charged ion or molecule.

aquifer - a body of rock or overburden that is sufficiently permeable to conduct groundwater and to yield economically significant quantities of water to wells and springs.

aquitard - a confining bed that retards but does not prevent the flow of water to or from an adjacent aquifer.

arete - a jagged, knife-edged ridges or crest.

artesian - groundwater confined under hydrostatic pressure.

bioturbation - the churning and stirring of a sediment by organisms.

bituminous - containing much organic or carbonaceous matter.

boreal - pertaining to the northern biotic area (or Boreal region) characterized by *tundra* and *taiga* and dominated by coniferous trees.

capacity - the potential sediment load a stream can carry.

calcite - a common rock forming mineral: $CaCO_3$, the principal constituent of limestone.

calcium bicarbonate - $Ca(CO_3)_2$.

cation - a positively charged ion or molecule.

cephalopod - any marine mollusc belonging to the class Cephalopoda.

chronostratigraphic - a body of rock established to serve as the material reference for all rocks formed during the same span of time.

cladoceran - any crustacean belonging to the order Cladocera (with a univalve carapace bent along the back giving it a bivalve appearance). Commonly found in fresh- to brackish-water postglacial deposits.

competence - the size of particles a stream can transport under a given set of hydrologic conditions.

continental drift - the slow, lateral movements of continents across the Earth's surface.

delta - a body of sediment deposited by a stream where it flows into standing water, commonly forming a triangular or fan-shaped plain of considerable area.

debris flow - the downslope movement of unconsolidated sediments.

denudation - the sum of the weathering, mass-wasting, and erosional processes that result in the progressive lowering of the Earth's surface.

diamict - a non-genetic term describing any poorly-sorted deposit consisting of mud to boulder-sized particles (see also till).

diatom - microscopic, single-celled plant of the class Bacillariophyceae, which grows in both marine and fresh water.

discharge area - area where subsurface water is discharged to streams or to bodies of surface water.

dolomite - a common rock forming mineral: $CaMg(CO_3)_2$, the principal component of dolomite (rock).

dolostone - term for the sedimentary rock dolomite (to avoid confusion with the mineral of the same name).

downwarping - subsidence of a regional area of the Earth's crust.

drift - a general term applied to all rock material transported by a glacier and deposited directly by or from the ice, or by running water emanating from the glacier.

drumlin - a streamlined hill consisting of till and other sediments, and elongated parallel with the direction of ice flow.

drumlinoid - a crudely streamlined rock knob or drift deposit whose form approaches that of a true drumlin.

earth science - an all-embracing term for sciences related to the Earth.

eccentricity - (of Earth's orbit) the degree to which the shape of the Earth's orbit departs from perfect circularity.

epicontinental - situated on the continental shelf or on the continental interior.

fabric - the orientation (or lack of) in space of the elements (discrete particles, crystals, cements) of which a sedimentary rock is exposed.

fault - a fracture along which the opposite sides have been displaced relative to each other.

fissile - capable of being easily split along closely space planes (exhibiting fissility); said of bedding that consists of laminae less than 2 mm in thickness.

fissility - a general term for the property possessed by some rocks of splitting easily into thin layers along closely spaced, roughly planar and approximately parallel surfaces.

flame structures - a sedimentary structure consisting of wave- or flame-shaped plumes of mud that have been squeezed irregularly upward into an overlying layer.

floodplain -the part of any stream valley which is inundated during floods.

formation - a body of rock distinctive enough on the basis of physical properties to constitute a basic unit for geologic mapping

fluted - lineations or streamline grooves and ridges parallel to the direction of ice movement, formed in newly deposited till or older drift.

fluvial - of, or pertaining to streams or rivers, especially erosional and depositional processes of streams and the sediments and landforms resulting from them.

fossiliferous - containing fossils.

gastropod - any mollusc belonging to the class Gastropoda, characterized by a distinct head with eyes and tentacles and, in most cases, by a single calcarious shell that is closed at the apex.

glaciofluvial - pertaining to the meltwater streams flowing from wasting glacier ice and especially to the deposits and landforms produced by such streams.

glacio-isostatically depressed - crustal adjustment to loading (depressed) and unloading (decompressed) that is attributed to addition and removal of glacier ice.

glaciolacustrine - pertaining to, derived from, or deposited in glacial lakes; especially said of the deposits and landforms composed of suspended material brought by meltwater streams flowing into lakes bordering the glacier or direct input of material by the glacier into lakes at the ice margin.

graptolite - any colonial marine organism belonging to the class Graptolithina, characterized by a cup- or tube-shaped, highly resistant exoskeleton of organic composition. Commonly found in black shales.

groundwater - subsurface water that occurs beneath the water table in soils and geologic formations that are fully saturated.

groundwater recharge - waters infiltrating the surface, replenishing groundwater supply.

hummocky cross-stratification - a type of cross-stratification consisting of domed, subparallel laminations or beds which comprise in three dimensions a radially symmetrical mound. Formed by reworking of bottom sediments by storm waves in shallow (< 20 m) water.

ice sheet - a continent-sized mass of ice.

ice-wedge cast - a fossil ice wedge; a sedimentary structure formed by the filling of the space formerly occupied by an ice wedge that had melted. The sediment fill may be wedge-shaped or very irregular.

interglacial - pertaining to or formed during the time interval between two successive glacial epochs or between two glacial stages. Implies both the melting of ice sheets to about their present level, and the maintenance of a warm climate for a sufficient length of time to permit vegetational changes to occur.

interstadial - pertaining to, or formed during an interstade, a warmer substage of a glacial stage, marked by a temporary retreat of the ice OR a climatic episode within a glaciation during which a secondary recession of a still stand of glaciers took place.

isotopes - atoms having the same atomic number but a different number of neutrons (e.g. ^{16}O, ^{18}O).

kame - a landform consisting of stratified sand and gravel deposited by an ice marginal stream and subsequently formed into an irregular mound, hummock, knob or short ridge by melting of buried ice.

kamiform - said of terrain having an irregular, surface topography consisting of hummocks and depressions.

lacustrine - pertaining to, produced by, or formed in a lake.

limestone - a sedimentary rock consisting chiefly (more than 50%) of calcium carbonate.

littoral - pertaining to the depth zone between the shore and a depth of about 200 m.

longshore drift - transport of sediments in the nearshore zone, parallel to the coastline.

made-ground - man made land, an area artificially filled with earth materials which may contain refuse.

mass wasting - a general term for the dislodgement and downslope transport of soil and rock material under the direct application of gravitational body stresses.

member - a rock stratigraphic unit that is a subdivision of a formation.

mollusc - a solitary invertebrate belonging to the phylum Mollusca, characterized by a nonsegmented body that is bilaterally symmetrical and by a radially or biradially symmetrical mantle and shell.

moraine - a mound, ridge, or other distinct accumulation of typically poorly sorted, glacially derived sediments deposited at the margin of a glacier.

neotectonic - refers to recent deformation or movement of bedrock surfaces, joints or faults and Quaternary sediments.

oligichaete - any worm belonging to the class Oligichaetae, characterized by a segmented body.

onlap - an overlap characterized by the regular and progressive pinching out, toward the margins or shores of a depositional basin, of the sedimentary units within a conformable sequence of rocks, in which the boundary of each unit is transgressed by the next overlying unit and each unit in turn terminates farther from the point of reference.

orogeny - the process by which large regions of the Earth's crust are deformed and uplifted to form mountains.

ostracods - any aquatic crustacean belonging to the subclass Ostracoda, characterized by a bivalve, generally calcified carapace with a hinge along the dorsal margin (generally 0.4 - 1.5 mm long).

outsize - a sediment particle which is substantially greater than the mean grain size.

outwash - stratified drift deposited by streams of meltwater.

outwash plains - a broad, gently sloping sheet of outwash (chiefly sand and gravel, removed or 'washed out' from a glacier by meltwater streams) deposited by meltwater streams flowing in front of or beyond a glacier.

overburden - the loose soil, silt, sand, gravel or other unconsolidated material overlying bedrock, either transported or formed in place.

overconsolidated - consolidation resulting from dewatering or from pressure of overburden that has since been removed by erosion.

pelecypod - any benthic aquatic mollusc belonging to the class Pelecypoda, characterized by a bilaterally symmetrical bivalve shell, a hatchet-shaped foot and sheetlike gills.

petroliferous - bearing crude oil or natural gas.

planar cross-bedded - cross-bedding in which the lower bounding surfaces are planar surfaces of erosion, resulting from bevelling (an act or instance of cutting across a geologic structure or landform) and subsequent deposition.

point bars - one of a series of low, arcuate ridges of sand and gravel developed on the inside of a growing meander by the slow addition of individual accretions accompanying migration of the channel toward the outer bank.

prececession - (of the Earth's orbit) a progressive change in the distance between the Earth-Sun distance for a given date.

proglacial - immediately in front of or just beyond the outer limits of a glacier or ice sheet, generally at or near its margin.

progradation - the outward extension of a shoreline into a lake or the sea due to sedimentation.

radiometric - pertaining to the measurement of geologic time by the study of parent and/or daughter isotopic abundances and known disintegration rates of the radioactive parent isotopes.

recharge area - the area where water infiltrates the surface and enters the groundwater flow system.

sag basins - depression occurring at contact between an aquifer and underlying less permeable unit which acts to focus seeping groundwaters.

sand volcanoes - an accumulation of sand resembling a miniature volcano or low volcanic mound (maximum diameter 15 m), produced by expulsion of liquefied sand to the sediment surface.

sedimentary dykes - a tabular mass of sedimentary material that cuts across the structure or bedding of pre-existing rock in the manner of an igneous dike. Formed by the filling of a crack or fissure from below, above or laterally, by forcible injection or intrusion of sediments under abnormal pressure.

shale - a fine grained detrital sedimentary rock, formed by the consolidation (especially by compression) of clay, silt or mud. It is characterized by finely laminated structure, which imparts a fissility approximately parallel to bedding.

shoreface - narrow, rather steeply sloping zone lakeward from the low water shoreline, permanently covered by water, over which beach sands and gravels more with changing wave conditions.

slope wash - soil and rock material that is or has been transported down a slope by mass wasting assisted by running water not confined to channels.

sodium bicarbonate - $Na(CO_3)_2$.

spring sapping - the erosion of a hillside around the fountainhead of a strongly flowing stream, causing small landslides and resulting in the retreat of the valley head.

stadial - pertaining to or formed during a stade (a substage of a glacial stage marked by a glacial readvance).

stratum (plural = strata) - a tabular layer of sedimentary rock distinct from layers above and below it.

striations - scratches or grooves, generally parallel, inscribed on a rock surface by glaciers (glacial striations).

subaerial processes - said of conditions and processes that exist or operate in the open air on or immed[illegible]ly adjacent to the land surface or of features and materials that are formed or situated on the land [illegible]face.

subaqueous - said of conditions and processes, or of features and deposits, that exist or are situated in or under water, especially fresh water as in a lake or stream.

sub-littoral - said of that part of the littoral zone that is between low tide and a depth of about 100 m.

swaley cross-stratification - a type of cross-stratification consisting of concave-upward, subparallel laminations and beds which have a basin-like configuration in three dimensions. Formed by reworking of bottom sediments by storm waves, usually in shallow (< 20 m deep) water.

thermoluminescence dating - a method of dating applicable to materials that have once been heated. A fraction of the energy released by decay of long-lived radioactive nuclides is stored as trapped electrons, and this energy is released as light upon heating. The age of a sample can be determined if the natural thermoluminescence is measured, the thermoluminescence induced by a known radiation dose is measured, and the radiation dose received by the sample per unit time in the past is estimated.

till - dominantly unsorted and unstratified glacial diamict emplaced directly by and underneath a glacier without subsequent reworking by meltwater, and consisting of a heterogeneous mixture of clay, silt, sand, gravel and boulders ranging widely in size and shape.

till plain - an areally extensive, flat to undulating till surface, generally characterized by streamlined landforms such as drumlins and flutes and low relief moraines.

trilobite - any marine arthropod belonging to the class Trilobita, characterized by a three-lobed, ovoid to subelliptical exoskeleton.

trough cross-bedded - cross-bedding in which the lower bounding surfaces are curved surfaces of erosion, it results from local scour and subsequent deposition.

type locality - the place where a geologic feature was first recognized and described.

unconformably - said of strata or stratigraphy exhibiting the relation of unconformity to the older underlying rocks, not succeeding the underlying rocks in immediate order of age or not fitting together with them as parts of a continuous whole.

varves - a thin pair of graded glaciolacustrine layers seasonally deposited, usually by meltwater streams, in a glacial lake or other body of still water in front of a glacier (normally includes a lower 'summer' layer consisting of relatively coarse-grained, light-coloured sediment [usually sand or silt] produced by rapid melting of ice in the warmer months which grades upward into a thinner 'winter' layer, consisting of very fine-grained [clayey] often organic, dark sediment slowly deposited from suspension in quiet water while the streams were ice-bound.

wave ripples - a symmetric ripple mark with a sharp, narrow, relatively straight crest between broadly rounded troughs, formed by the orbital or to-and-fro motion of water agitated by oscillatory waves.

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APPENDIX A: FAUNA OF THE WHITBY FORMATION (UPPER AND MIDDLE MEMBERS; AFTER LIBERTY 1969)

Upper Member

Annelida:
- *Cornulites* cf. *progressus*
- *Protoscolex* sp.

Brachiopoda:
- *'Dalmanella' fultonensis lorrainensis*
- *Leptaena* cf. *moniquensis*
- *Leptobolus insignis*
- *Lingula* cf. *curta*
- *Pholidops cincinnatiensis*
- *Sowerbyella* cf. *rugosa clarkesvillensis*

Bryozoa:
- *Aspidopora* sp.
- *Paleschara beani*
- *Spatiopora delicatula*

Cephalopoda:
- cf. *Cycloceras persculptum*
- *Geisonoceras tenuistriatum*
- cf. *Protokionoceras oneidaense*

Gastropoda:
- *Archinacella* cf. *subcarinata*
- *Liospira* cf. *micula*
- *Tetranota* cf. *rugosa*

Graptozoa:
- *Climacograptus prolificus*
- *Climacograptus rougensis*
- *Diplograptus montis*
- *D.* cf. *vespertinus*
- *Glossograptus quadrimucronatus*
- *Leptograptus flaccidus*
- *Mastigograptus tenuiramosus*

Ostracoda:
- *Aparchites minutissimus*

Pelecypoda:
- *Cleidophorus neglectus*
- *C. planulatus*
- *Ctenodonta filistriata*
- *Lyrodesma conradi*

Trilobita:
- *Cryptolithus bellulus*
- *C. lorrainensis*
- *C.* cf.*recurvus*
- *C. tessellatus*
- *Flexicalymene meeki*
- *Homotelus stegops*
- *Triarthrus huguensis*
- *T. spinosus rougensis*

Middle Member

Brachiopoda:
- *Leptobolus insignis*
- *Lingula* sp.

Cephalopoda:
- cf. *Cycloceras persculptum*
- *Geisonoceras tenuistriatum*
- *'Orthoceras'* cf. *transversum*

Graptozoa:
- *Climacograptus typicalis*
- *Glossograptus quadrimucronatus*

Ostracoda:
- *Primitiella ulrichi*

Pelecypoda:
- cf. *Prolobella corrugata*

Trilobita:
- *Triarthrus canadensis*
- *T. spinosus rougensis*

APPENDIX B: FAUNA AND FLORA OF THE SCARBOROUGH FORMATION (PARTIAL LISTING; AFTER KARROW 1967)

Diatomaceae:

Navicula
Pinnularia
Stauroneis

Gastropoda:

Physa sp.
Succinea sp.
Valvata tricarinata Say

Mollusca:

Limnaea sp.
Planorbis sp.
S. Fabale
Sphaerium rhomboideum
Valvata tricarinata

Musei:

Bryum
Fontinalis
Hypnum commutatum
H. revolvens/
Hypnum sp.

Pelecypoda:

Spaerium striatinum
Sphaerium sp.

Plantae:

Abies balsamea
Abies sp.
Acer sp.
Alnus sp.
Ambrosia sp.
Artemisia sp.
Betula sp.
Brasenia purpurea
Carex aquatilis
C. utriculata
Carpinus sp.
Carya sp.
Caryophyllaceae
Castanea sp.
Ceratophyllum demersum
Chara sp.
Chenopodium sp.
Chenopodiaceae
Corylus sp.
Drepanocladus vernicosus
Equisetum
Ericaceae
Fagus sp.
Fraxinus sp.
Fungus spores
Gramineae
Hygrohypnum palustre?
Hylocomium
Ilex sp.
Larix americana
Larix sp.
Lycopodium annotinum
Lycopodium sp.
Menyanthes sp.
Myrica sp.
Myriophyllum sp.
Nuphar sp.
Nymphaea sp.
Osmunda sp.
Picea glauca
P. mariana
Picea sp.
Pinus banksiana
Polygonum sp.
Polypodiaceae
Potamogeton sp.
Prunus sp.
P. strobus
Quercus sp.
Rubus chamaemorus
Salix sp.
Scirpus fluviatilis
Shepherdia sp.
Sphagnum spores
Sparganium sp.
Tilia sp.
Tsuga canadensis
Typha latifolia
Ulmus sp.
Vaccinium oxycoccus
V uliginosum

APPENDIX C: SUMMARY OF REGIONAL GEOLOGIC HISTORY

GEOLOGICAL TIME PERIOD	SIGNIFICANT EVENT	AGE (Y.B.P.)
CENOZOIC		
Quaternary Holocene	Downcutting of river systems draining into Lake Ontario, formation and abandonment of river terraces. Deposition of fluvial sediments, marsh and organic deposits.	present - 10,000
	-----MINOR EROSIONAL INTERVAL-----	
L. Wisconsinan	Retreat of ice from the Ontario basin, formation of high-level glacial Lake Iroquois and associated beach terraces and deposits. Development of ephemeral, ice-marginal lakes (Peel Ponds) and early postglacial drainage system.	12,000 - 13,000
	-----MINOR EROSIONAL INTERVAL-----	
	Repeated advances of Simcoe and Ontario lobes into the Ontario basin. Deposition of the Halton Till, formation of drumlins and flutes, building of the Oak Ridges moraine.	13,000 - 30,000
	-----EROSIONAL INTERVAL-----	
M. Wisconsinan	Interstadial period; continued glacio-lacustrine sedimentation (Thorncliffe Fm., Seminary and Meadowcliffe diamicts) in high-level, proglacial lake.	30,000 - 54,000
E. Wisconsinan	Formation of the Scarborough delta (Scarborough formation & Pottery Rd. formation). Limited extent of ice in the Ontario basin. Deposition of stony muds in proglacial lake (Sunnybrook diamict).	54,000 - 80,000
	-----MINOR EROSIONAL INTERVAL-----	
Sangamonian	Interglacial period; warm climate, lacustrine deposition (Don Fm.)	125,000
	-----EROSIONAL INTERVAL-----	
Illinoian	Extensive ice cover in Ontario basin, deposition of York Till.	>125,000
	-----MAJOR EROSIONAL HIATUS-----	
PALEOZOIC		
U. Ordovician	Continued tectonic uplift, marine transgression with deposition of deep water shales (L. Whitby Fm.) followed by recession of seas and deposition of shales in moderately shallow waters (M. and U. Whitby, and Georgian Bay Fm.'s)	458,000,000 - 438,000,000
	-----MINOR EROSIONAL INTERVAL-----	
M. Ordovician	Repeated collision of island arc with eastern North America resulting in downwarping of the continental crust and flooding of continental interior. Deposition of shallow water carbonates (Simcoe Group).	458,000,000 - 478,000,000

APPENDIX C: QUATERNARY STRATIGRAPHIC UNITS BETWEEN TORONTO AND BOWMANVILLE

WEST <----------> EAST					
STAGE	Age (years B.P.)	Toronto Area	Scarborough Bluffs and Rouge River area	Oshawa - Port Hope	Environmental Summary
Postglacial	< 13 000		Iroquois Sands		High-level (60 m +) lake in glacially dammed and isostatically depressed basin
Late Wisconsinan	< 30 000	Willowdale Till Lansdowne Till St. George Till Pape Till	Leaside Till Halton Till	Bowmanville Till	Shallow Lacustrine and glaciofluvial sedimentation before and after subglacial deposition of streamlined lodgement till plain by a regional extensive Laurentide Ice Sheet after 30 000 BP.
Early - Mid-Wisconsinan	< 80 000	Coxwell, Greenwood Tills Queen's Park Silts Museum Varved Clays Sherbourne Till Bartlett Till	Danforth Beds Meadowcliffe Till Seminary Till Thorncliffe Sand Bloor Beds Sunnybrook Till	Bond Head Till Clarke Deposits Port Hope Till	Episodes of proglacial sedimentation in high-level (95 m +) lake alternating with storm-influenced delta progradation. Limited regional extent of Early and Mid-Wisconsinan Laurentide Ice Sheet with margin oscillating in frontal lakes.
Sangamonian - earliest Wisconsinan	c. 125 000	Willowdale Sands	Pottery Road Formation		Unresolved but possibly glaciofluvial sedimentation and erosion on delta (see below) or episode of lake-level lowering.
			Scarborough Sands Scarborough Silts and Clays Don Formation		Interglacial sedimentation in high-level (20 m +), storm-dominated lakeshore-face. Climatic cooling (cool to boreal) accompanied by rising lake level (to 45 m +) and delta progradation of sands over silts and clays.
Illinoian	> 125 000	York Varves	York Till		Subglacial - proglacial sedimentation below regionally extensive ice sheet.

MAPS
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CARTES
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